MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. XLVII. FEBRUARY 11, 1887 No. 4

J. W. L. GLAISHER, M.A., F.R.S., President, in the Chair.

REPORT OF THE COUNCIL TO THE SIXTY-SEVENTH ANNUAL GENERAL MEETING OF THE SOCIETY.

The following table shows the progress and present state of the Society:—

	Compounders	Annual Subscribers	Mathematical Society	Total Fellows	Associates	Patron	Grand Total
December 31, 1885	224	374	3	601	48	1	650
Since elected	+3	+20	...	...	+2	...	...
Deceased	−4	−12	...	...	−1	...	...
Resigned	...	−5	...	...	...	...	...
Expelled	...	−4	...	...	...	...	...
Removals	+2	−2	...	...	...	...	...
December 31, 1886	225	371	3	599	49	1	649

Mr. Common's Account as Treasurer of the Royal

RECEIPTS.

	£	s.	d.	£	s.	d.
Balance at Bankers', Jan. 1, 1886	395	2	7			
„ in hand of Assistant Secretary on account of Turnor and Horrox Funds	22	7	5			
				417	10	0
Half-year's dividend on £7,500 Consols	108	15	0			
„ „ £5,700 New 3 per cent. Stock	82	13	0			
„ „ £7,500 Consols	108	15	0			
„ „ £5,700 New 3 per cent. Stock	82	13	0			
Dividends on £500 Metropolitan Stock	14	10	0			
				397	6	0
Received on account of Subscriptions:						
Arrears	161	14	0			
260 Annual Contributions for 1886	546	0	0			
4 „ „ 1887	8	8	0			
21 Admission Fees	44	2	0			
18 First Contributions	31	10	0			
				791	14	0
Composition Fees				105	0	0
Sales of Publications:						
At Williams and Norgate's, 1885	29	15	7			
At Society's Rooms, 1886	38	7	9			
				68	3	4
				£1,779	13	4

Audited and found correct, Jan. 8, 1887.

ROBT. BRYANT.
ROBT. J. LECKY.
HERBERT SADLER.

Astronomical Society, from Dec. 31, 1885, *to Dec.* 31, 1886.

EXPENDITURE.

	£	s.	d.	£	s.	d.
Assistant Secretary: Salary	225	0	0			
,, ,, for assistance in editing Society's Publications ...	50	0	0			
				275	0	0
Income Tax and House Duty				13	2	6
Fire Insurance				7	16	6
Printing	577	11	0			
Engraving and Lithography	4	8	0			
Computation of Ephemerides in *Monthly Notices* ...	50	0	0			
				631	19	0
Turnor and Horrox Funds: purchase of Books for Library	21	1	5			
Binding Books in Library	19	16	9			
Preparation of Library Catalogue	25	0	0			
				65	18	2
House Expenses	34	13	5			
Wages	31	4	0			
Postage, &c.	58	13	1			
Carriage of Parcels, &c.	2	6	6			
Stationery and Office Expenses	6	12	9			
Expenses of Meetings	20	0	0			
Coals and Gas	56	7	9			
Fittings and Repairs...	12	16	6			
Sundries	4	12	11			
				227	6	11
Gold Medals				52	10	0
Portrait of Sir Isaac Newton				18	18	0
Lee Fund				5	0	0
Mrs. Jackson Gwilt's Annuity				8	19	0
Bankers' Commission on Cheques	0	2	4			
Cheque Book	0	8	4			
				0	10	8
Balance at Bankers', Dec. 31, 1886	434	2	9			
Cheque not Credited in Pass Book	2	2	0			
Balance in hand of Assistant Secretary on account of Turnor and Horrox Fund	21	6	0			
,, in hand of Assistant Secretary on Petty Cash Account	1	18	3			
				459	9	0
Paid Balance due to Assistant Secretary, Jan. 1, 1886, on Petty Cash account				13	3	7
				1,779	13	4

Assets and Present Property of the Society, Jan. 1, 1887.

	£	s.	d.	£	s.	d.
Balance at Bankers', including an amount of £40 16*s.* 3*d.*, being the accumulated interest of the Lee Fund, Dec. 31, 1886	434	2	9			
Cheque not Credited in Pass Book	2	2	0			
„ in hand of Assistant Secretary on account of Turnor and Horrox Funds	21	6	0			
„ in hand of Assistant Secretary on Petty Cash account	1	18	3			
				459	9	0
Due on account of Subscriptions :						
4 Contributions of 4 years' standing ...	33	12	0			
14 „ 3 „ ...	88	4	0			
30 „ 2 „ ...	126	0	0			
67 „ 1 year's standing ...	140	14	0			
3 Admission Fees and First Contributions ...	9	9	0			
	397	19	0			
Less 4 Contributions paid in advance ...	8	8	0			
				389	11	0
Due from Messrs. Williams and Norgate for sales of Publications during 1886				37	15	10

£7,500 Consols, including the Lee Fund, the Turnor Fund, and the Horrox Memorial Fund.

£5,700 New 3 per cent. Stock, including Mrs. Jackson Gwilt's gift (£300).

£500 Metropolitan Board of Works Stock.

Astronomical and other Manuscripts, Books, Prints, Instruments; and Furniture.

Unsold Publications of the Society.

Three Gold Medals.

Report of the Auditors.

We, being the duly appointed Auditors, beg to lay before this Annual General Meeting of the Royal Astronomical Society the following Report:—

We have examined the Treasurer's account, and have found and certified the same to be correct. The receipts and expenditure for the past year are as stated in the Treasurer's account. The cash in hand on December 31, 1886, including the balance at the bankers', amounted to 459*l.* 9*s.*

The funded property is the same as at the end of last year.

The books, instruments, and other effects have been examined and found to be in a satisfactory condition, so far as their safe keeping is concerned.

We have laid on the table a list of the names of those Fellows who are in arrear for sums due at the last Annual General Meeting, with the amount due against each Fellow's name.

(Signed) Robt. J. Lecky,
Robt. Bryant,
Herbert Sadler.

Stock in hand of volumes of the *Memoirs*:—

Vol.	At Society's Rooms	At Williams & Norgate's	Vol.	At Society's Rooms	At Williams & Norgate's
I. Part 1	7	...	XXIX.	411	...
I. Part 2	43	...	XXX.	159	1
II. Part 1	56	...	XXXI.	143	...
II. Part 2	21	...	XXXII.	154	1
III. Part 1	67	1	XXXIII.	164	...
III. Part 2	86	1	XXXIV.	164	4
IV. Part 1	80	3	XXXV.	108	6
IV. Part 2	92	3	XXXVI.	198	10
V.	106	4	XXXVII. Part 1	339	8
VI.	125	3	XXXVII. Part 2	287	8
VII.	145	3	XXXVIII.	276	1
VIII.	127	3	XXXIX. Part 1	248	4
IX.	134	3	XXXIX. Part 2	253	4
X.	146	...	XL.	268	2
XI.	151	...	XLI.	417	1
XII.	159	...	XLII.	239	4
XIII.	163	...	XLIII.	243	1
XIV.	370	3	XLIV.	224	1
XV.	140	...	XLV.	260	1
XVI.	165	...	XLVI.	242	3
XVII.	147	1	XLVII. Part 1	3	...
XVIII.	146	...	XLVII. Part 2	19	...
XIX.	152	...	XLVII. Part 3	2	...
XX.	142	...	XLVII. Part 4	10	...
XXI. Part 1	314	...	XLVII. Part 5	10	...
XXI. Part 2	99	...	XLVII. Part 6	10	...
XXI. 1 & 2 (together)	61	...	XLVII.	240	2
XXII.	164	...	XLVIII. Part 1	310	3
XXIII.	150	...	XLVIII. Part 2	348	3
XXIV.	156	...	Index to *Memoirs*	645	1
XXV.	166	...			
XXVI.	172	...			
XXVII.	422	...			
XXVIII.	383	...			

Stock in hand of volumes of the *Monthly Notices* :—

Vol.	At Society's Rooms	At Williams & Norgate's	Vol.	At Society's Rooms	At Williams & Norgate's
I.	68	...	XXV.	7	...
II.	69	...	XXVI.	10	...
III.	...	...	XXVII.	3	...
IV.	...	...	XXVIII.	72	1
V.	...	...	XXIX.	51	...
VI.	37	...	XXX.	68	2
VII.	2	...	XXXI.	96	...
VIII.	139	2	XXXII.	118	5
IX.	25	2	XXXIII.	100	2
X.	174	1	XXXIV.	79	2
XI.	185	1	XXXV.	61	1
XII.	11	2	XXXVI.	32	1
XIII.	157	3	XXXVII.	39	3
XIV.	109	3	XXXVIII.	103	2
XV.	127	2	XXXIX.	108	1
XVI.	108	2	XL.	113	3
XVII.	137	1	XLI.	114	5
XVIII.	166	...	XLII.	122	2
XIX.	56	...	XLIII.	122	2
XX.	35	...	XLIV.	125	5
XXI.	18	...	XLV.	130	3
XXII.	33	...	XLVI.	137	4
XXIII.	19	...	Index to *Monthly Notices*	568	1
XXIV.	24	...			

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In addition to the above volumes of the *Monthly Notices*, the Society has a considerable stock of separate numbers of nearly all the volumes. With the exception, however, of Vols. XXXVI. to XLVI. no complete volumes can be formed from the separate numbers in stock.

Instruments belonging to the Society.

No. 1. The *Harrison* clock.
„ 2. The *Owen* portable circles, by Jones.
„ 3. The *Beaufoy* circle.
„ 4. The *Beaufoy* transit instrument.

No. 5. The *Herschel* 7-foot telescope.
„ 6. The *Greig* universal instrument, by Reichenbach and Ertel. The transit telescope, by Utzschneider and Fraunhofer, of Munich.
„ 7. The *Smeaton* equatoreal.
„ 8. The *Cavendish* apparatus.
„ 9. The 7-foot Gregorian telescope (late Mr. Shearman's).
„ 10. The variation transit instrument (late Mr. Shearman's).
„ 11. The universal quadrat, by Abraham Sharp.
„ 12. The *Fuller* theodolite.
„ 13. The standard scale, by Troughton and Simms.
„ 14. The *Beaufoy* clock, No. 1.
„ 15. The *Beaufoy* clock, No. 2.
„ 16. The *Wollaston* telescope.
„ 17. The *Lee* circle.
„ 18. The *Sharpe* reflecting circle.
„ 19. The *Brisbane* circle.
„ 20. The *Baker* universal equatoreal.
„ 21. The *Reade* transit.
„ 22. The *Matthew* equatoreal, by Cooke.
„ 23. The *Matthew* transit instrument.
„ 24. The *South* transit instrument.
„ 25. A sextant, by Bird (formerly belonging to Captain Cook).
„ 26. A globe showing the precession of the equinoxes.
The *Sheepshanks* collection :—
„ 27. (1) 30-inch transit instrument, by Simms, with level and two iron stands.
„ 28. (2) 6-inch transit theodolite, with circles divided on silver; reading microscopes, both for altitude and azimuth ; cross and siding levels; magnetic needle; plumbline; portable clamping foot and tripod stand.
„ 29. (3) Equatoreal stand and clock movement for $4\frac{6}{10}$-inch telescope (telescope lost) ; double-image micrometer; two wire micrometers; object-glass micrometer.
„ 30. (4) $3\frac{1}{4}$-inch achromatic telescope, with equatoreal stand; double-image micrometer; one terrestrial and three astronomical eyepieces.
„ 31. (5) $2\frac{3}{4}$-inch achromatic telescope, with stand; one terrestrial and three astronomical eyepieces.
„ 33. (7) 2-foot navy telescope.
„ 34. (8) Transit instrument of 45 inches focal length; with iron stand and also Ys for fixing to stone piers; two axis levels.
„ 35. (9) Repeating theodolite, by Ertel, with folding tripod stand.
„ 36. (10) 8-inch pillar sextant, by Troughton, divided on platinum, with counterpoise stand and artificial horizon.

No. 37. (11) Portable zenith telescope and stand, $2\frac{3}{4}$-inch aperture and 26 inches focal length; 10-inch horizontal circle and 8-inch vertical circle, read to 10″ by two verniers to each circle.

„ 38. (12) 18-inch Borda repeating circle, by Troughton, $2\frac{1}{8}$-inch aperture and 24 inches focal length; the circles divided on silver, the horizontal circle being read by four verniers, and the vertical circle by three verniers, each to 10″.

„ 39. (13) 8-inch vertical repeating circle, with diagonal telescope, by Troughton and Simms; circle divided on silver, reading to 10″; a 5-inch circle at eye-end, reading to single minutes; horizontal circle 9 inches diameter in brass, reading to single minutes.

„ 40. (14) A set of surveying instruments, consisting of a 12-inch theodolite for horizontal angles only, reading to 10″; two sets of adjusting plates; tripod stand with enclosed telescope; heavy stand for theodolite; Y piece of level; two large and three small ground-glass bubbles divided; level collimator, object-glass $1\frac{5}{8}$-inch diameter and 16 inches focal length; micrometer eyepiece, comb, and wires; mercury bottle and trough.

„ 41. (15) Level collimator with object-glass $1\frac{7}{8}$-inch diameter and 16 inches focal length; stand, rider-level, and fittings.

„ 42. (16) 10-inch reflecting circle by Troughton, reading by three verniers to 20″; counterpoise stand; artificial horizon, with mercury; two tripod stands.

„ 43. (17) Hassler's reflecting circle, by Troughton, with counterpoise stand.

„ 44. (18) 6-inch reflecting and repeating circle, by Troughton and Simms, contained in three boxes, two of which form stands. Circle divided on silver, reading to single minutes; two inside arcs divided to single degrees, 150 degrees on each side; artificial horizon and mercury.

„ 45. (19) 5-inch reflecting and repeating circle, by Lenoir, of Paris.

„ 46. (20) Reflecting circle, by Jecker, of Paris, 11 inches in diameter, with one vernier reading to 15″.

„ 47. (21) Box sextant; reflecting plane and level.

„ 48. (22) Prismatic compass, by Troughton and Simms.

„ 49. (23) Mountain barometer.

„ 50. (24) Prismatic compass, by Thomas Jones, mounted with a cylindrical lens.

„ 51. (25) Ordinary $4\frac{1}{2}$-inch compass with needle.

„ 52. (26) Dipping needle, by Robinson.

53. (27) Compass needle, mounted for variation.

No. 54. (28) Magnetic intensity needle, by Meyerstein, of Göttingen; a strongly fitted brass box with heavy magnet; filar suspension.

„ 55. (29) Box of magnetic apparatus.

„ 56. (30) Hassler's reflecting circle, by Troughton; a 10½-inch reflecting and repeating circle, with stand and counterpoise, divided on platinum with two movable and two fixed indices; four verniers reading to 10″.

„ 57. (31) Box sextant and glass plane artificial horizon, by Troughton and Simms.

„ 58. (32) Plane 2⅜-inch speculum, artificial horizon, and stand.

„ 59. (33) 2½-inch circular level horizon, by Dollond.

„ 60. (34) Artificial horizon, roof, and trough; the trough 8¼ by 4½ inches; tripod stand.

„ 61. (35) Set of drawing instruments, consisting of 6-inch circular protractor and common protractor, T-square; one beam compass.

„ 62. (36) A pantagraph.

„ 63. (37) A noddy.

„ 64. (38) A small Galilean telescope with object-glass of rock crystal.

„ 65. (39) Five levels.

„ 66. (40) 18-inch celestial globe.

„ 67. (41) Varley stand for telescope.

„ 69. (43) Telescope, with object-glass of rock crystal.

„ 71. Portable altazimuth tripod.

„ 72. Four polarimeters.

„ 74. Registering spectroscope, with one large prism.

„ 76. Two five-prism direct-vision spectroscopes.

„ 78. 9¼-inch silvered-glass reflector and stand, by Browning.

„ 79. Spectroscope.

„ 80. A small box, containing three square-headed Nicol's prisms; two Babinet's compensators; two double-image prisms; three Savarts; one positive eyepiece, with Nicol's prism; one dark wedge.

„ 81. A back-staff, or Davis' quadrant.

„ 82. A nocturnal or star dial.

„ 83. An early non-achromatic telescope, of about 3 feet focal length, in oak tube, by Samuel Scatliffe, London.

„ 84. A Hollis observing chair.

„ 85. Double image micrometer, by Troughton and Simms.

„ 86. 4½-inch Gregorian reflecting telescope, by Short, with altazimuth stand and 6-inch altitude and azimuth circles and two eyepieces.

„ 87. 3¼-inch Gregorian reflecting telescope with wooden tripod stand.

No. 88. Pendulum with 5-foot brass suspension rod, working on knife edges, by Thomas Jones.
„ 89. A Rhabdological Abacus. A contrivance invented by Mr. H. Goodwyn, consisting of a box filled with compartments, in which are square rods covered with numbers, which can be arranged so as to facilitate the labour of multiplying high numbers.
„ 90. An Arabic celestial globe of bronze, $5\frac{3}{4}$ inches in diameter.
„ 91. Astronomical time watchcase, by Professor Chevallier.
„ 92. 2-foot protractor, with two moveable arms, and vernier.
„ 93. Beam compass, in box.
„ 94. 2-foot navigation scale.
„ 95. Stand for testing measures of length.
„ 96. Artificial planet and star, for testing the measurement of a fixed distance at different position-angles.
„ 97. 12-cell Leclanché battery.
„ 98. 2 feet 6 inch navy telescope with object-glass $2\frac{1}{2}$ inches, by Cooke, with portable wooden tripod stand.
„ 99. 12-inch transit instrument, by Fayrer & Son, with level and portable stand.
„ 100. 9-inch transit instrument, with level and iron stand.
„ 101. Small equatoreal sight instrument, by G. Adams, London.
„ 102. Sun-dial, by Troughton.
„ 103. Sun-dial, by Casella.
„ 104. Sun-dial
„ 105. Box sextant, by Troughton and Simms.
„ 106. Prismatic compass, by Schmalcalder, London.
„ 107. Compass, by C. Earle, Melbourne.
„ 108. Prismatic compass, by Negretti and Zambra.
„ 109. Dipleidoscope, by E. Dent.
„ 110. Abney level, by Elliott.
„ 111. Pocket spectroscope, by Browning.
„ 112. Small brass astrolabe.
„ 113. Double sextant, by Jones.
„ 114. Two models, illustrating the effects of circular motions.
„ 115. A cometarium.
„ 116. A pair of 18-inch globes.
„ 117, „ 118. Two old sun dials.
„ 119. Specimens of Diffraction gratings, by Prof. W. A. Rogers.

No. 120. A 6-prism spectroscope, by Browning.
„ 121. Spitta's Improved maximum and minimum thermometer.
„ 122. A 6-inch speculum, with flat; the speculum said to be by Sir W. Herschel, and re-figured by Sir J. Herschel.
„ 123. A 6-inch refracting telescope, by Grubb, with 3 eyepieces.

The following instruments are lent, during the pleasure of the Council, to the undermentioned persons:—

No. 4. The *Beaufoy* transit instrument, to the Observatory, Kingston, Canada.
„ 22. The *Matthew* equatoreal, to Mr. J. Brett.
„ 23. The *Matthew* transit, to Captain W. Noble.
„ 29. (3) Equatoreal mounting, clock movement, and stand, to Mr. W. Peck.
„ 30. (4) $3\frac{1}{4}$-inch equatoreal and stand, to Mr. H. Sadler.
„ 34. (8) Transit instrument, to Prof. C. Pritchard.
„ 69. (43) Telescope, with rock-crystal object-glass, to Dr. W. Huggins.
„ 78. Two eyepieces, to Mr. R. T. A. Innes.

The Gold Medal.

The Council have awarded the Society's Gold Medal to Mr. G. W. Hill for his researches on the Lunar Theory. The President will lay before the Society the grounds upon which the award has been founded.

Lunar Computations.

The computations, made by means of the Government Grant of 320*l.* for the purpose of comparing the Greenwich lunar observations 1847 to 1861 with Hansen's *Tables de la Lune*, have been completed, and will shortly be published.

Obituary.

The Council regret that they have to record the loss by death of the following Fellows and Associate during the past year:—

Fellows:—Major-General J. T. Boileau.
W. W. Boreham.
D. T. Evans.
W. S. Gillett.
George Hamilton.
R. J. Mann.
Rev. J. Pearson.
H. S. Redpath.
Rev. S. H. Saxby.
Admiral Sir C. F. A. Shadwell.
David Smith.
Captain F. Smith.
Edwin Story.
Rev. S. K. Swann.
C. G. Talmage.
William Tomlinson, jun.

Associate:—Theodor von Oppolzer.

Major-General John Theophilus Boileau, R.E., F.R.S., was born on May 26, 1805, at Calcutta, where his father, Mr. Thomas Boileau, was chief magistrate. This family claim descent from Étienne Boileau, Lord of Castelnau and St. Croix, who was left by Louis IX. as Constable and Provost of France when he went crusading; and Jacques Boileau, the poet, through Charles, Baron of Castelnau, who was driven from France at the time of the Revocation of the Edict of Nantes.

Mr. Boileau died in 1806, and his widow, with her two sons, John and Henry, then came to England and settled at Bury St. Edmunds, where the boys attended the grammar school, under Mr. Blomfield, at which John is said to have exhibited great capacity for languages. Soon after he was fourteen he received a nomination to a cadetship at Addiscombe, from which he passed brilliantly into the Bengal Engineers in December 1820. After the usual course of training at Chatham, under Sir C.

Pasley, he sailed for India, and reached Calcutta in September 1822, when little more than seventeen years of age. His energies were soon employed on the duties of the corps in building and repairing barracks, churches, bridges, and roads; and he soon acquired a reputation for the excellence of his work.

In 1836 he published in India (by lithography) "Traverse Tables to every Minute of the Quadrant"; and in 1839, when in England on furlough, these were printed and republished in London. In this latter year the Honourable Court of Directors of the East India Company selected Lieutenant Boileau for the charge of one of the three observatories which they undertook to support for magnetic and meteorological research. Simla was assigned as the charge of Lieutenant Boileau, and he was also directed to superintend the construction and despatch of instruments for the three observatories. After instruction by Prof. Humfrey Lloyd at Dublin, Lieutenant Boileau and the other two superintendents embarked (with the instruments) for India at the end of February 1840; and he finally reached Simla in October of that year, after leaving his colleagues and their instruments at Madras. During the voyage a series of meteorological observations was kept up, and on the way from Calcutta Boileau made observations of magnetical data at places at which he stopped. Work was commenced soon after his arrival at Simla in a temporary building, and the erection of the more permanent one was begun.

During the period prescribed for observation it appears that periodical abstracts were sent to Dr. Lloyd and the Royal Society, and Colonel Boileau, after the observatory was closed, was employed, in addition to other duties, till his retirement early in 1857, in reducing and printing his observations. On his leaving India the instruments and records were placed in store, and, having got mixed up with inflammable articles, the whole were in 1858 destroyed by fire. A portion of the meteorological results were published at Madras in 1851, and a further portion were published under General Boileau's care in 1872 by a grant from the India Office, procured by the Royal Society.

During his residence at Simla, General Boileau published from the Observatory press a set of astronomical, magnetic, and meteorological tables; some logarithmic tables and tables for computing time from extra-meridian observations; besides some other works of purely Indian interest.

After arriving finally in England in 1857, General Boileau's energies were devoted to such useful and charitable work as he could find. He soon became a member of the Committee of the Soldiers' Daughters' Home, and afterwards became Chairman. Later he joined that of the Royal School for Officers' Daughters. In 1860 he became a member of the 1st Middlesex (Victoria) Rifles, and served in that corps for six years as a private till his health prevented his longer attending regularly to drills, parades, &c. In 1867 he became a member of the Kensington Vestry,

and served zealously for thirteen years, earning the respect of his fellow vestrymen by his good sense, experience, and courtesy.

With endless humour and perpetually overflowing spirits, John Boileau, during his Indian career, was widely known for his eccentricities and practical jokes. Men would believe him capable of any joke that was not unkind. But he always had the confidence and regard of all who came in contact with him. Sir Henry Lawrence was among his companions at Addiscombe, and was his intimate friend to the last, while, in a long residence of seventeen years at Simla, he was brought into close contact with the rulers of India during that time without making any but friends; and so it would seem to have been after his settling in England. His fellow vestrymen, the members of the boards with which he was connected, and the staff and pupils of the schools he managed were all represented among the mourners at his funeral.

General Boileau was elected a Fellow of the Royal Society in January 1840. He served on the Council of the Royal Society, and was their representative on the governing body of Christ's Hospital. He died on November 9 last, after an illness of about six months.

He was elected a Fellow of this Society January 10, 1840.

William Wakeling Boreham was born at Haverhill, in Essex, on March 3, 1804, and received his early education at Saffron Walden, where he soon displayed great talent for mathematics and music.

Following his father's tastes, he at first became a brewer, and was in business in London and afterwards in Manchester; he subsequently returned to Haverhill, where he erected an observatory, and devoted himself industriously to observations of comets and minor planets. Many of his observations were published in the early volumes of the *Monthly Notices*.

Mr. Boreham was an ardent admirer of all science, and in his early life tried hard to promote the higher education of those in his native place. In later life he devoted his energies to education in all its branches.

He was for many years a Fellow of the Anthropological Society.

He was elected a Fellow of this Society April 11, 1845.

George Hamilton was born in Belfast in 1813. Removing to Liverpool at an early age, he was apprenticed to Mr. Bartain Haigh, builder. Soon after completing his term he was offered an appointment as architect, which he declined, having found his vocation to be that of a teacher. In 1836 he was appointed master of Mount Pleasant Schools, and amongst the children of the poor he worked out for several years his ideal course of instruction, which included, in addition to the usual branches, algebra, as far as quadratic equations, geometry, including the

first and second books of Euclid, and weekly lectures on chemistry and natural philosophy to both boys and girls.

While thus engaged he was appointed assistant and afterwards head master of the mathematical department of the evening school of the Liverpool Institute. From this class sprang "The Working Men's Science Association," to which Mr. Hamilton lectured nearly every week for two years to a working-class audience averaging 400 persons. In 1844 Mr. Hamilton lectured in Liverpool, Leeds, Bradford, and Chorley on "The Use of Science to Working Men," his aim being to establish free public evening lectures in every town in the kingdom, and to organise science teaching in every elementary school. But public opinion was then against the innovation. Mr. Hamilton was associated with the Liverpool Institute from 1840 to 1879 (when a serious accident obliged him to resign all his professional duties), successively holding the appointments of Teacher of Architectural Drawing and Building Construction, Teacher of Mathematics, Lecturer on Chemistry and Natural Philosophy in both Blackburne House and the High School, and in 1856 Professor of Chemistry in Queen's College (in connection with the London University).

In 1850 he was appointed first Lecturer on Chemistry and Teacher of Practical Pharmacy to the Liverpool Chemists' Association.

In 1856 he was elected a member of the Liverpool Compass Committee, to investigate the causes of deviation of the compass in iron ships.

He designed a self-registering compass, for recording the course of a ship at sea, indicating every change of tack and the exact time of change for the whole voyage. He also invented a self-registering thermometer, and a gas transferrer, or siphon, for transferring small quantities of gas for accurate measurement.

Mr. Hamilton was widely known as a teacher of science, and for many years successfully carried out a scheme for delivering a regular and systematic course of scientific instruction in middle-class schools—a task attempted by many before him, and rendered arduous from the expense and delicacy of much of the apparatus required, the difficulty of conveying it from place to place, the mental strain entailed by an average of twelve lectures weekly, and by the diversity of subjects, the course embracing astronomy, chemistry, geology, and natural philosophy. Nor, in his zeal for science, were the languages forgotten, each day having its apportioned task of classics and modern languages.

For several years, until prevented by failing health, he conducted the examinations for the Science Department of the Liverpool Council of Education.

Mr. Hamilton was a member of the Chemical Society and of the Society of Arts. He wrote "Glimpses of Nature," "Social Science," "Gravitation," "Physical Science," "On the Con-

servation of Force," "On Iron," "The Chemistry of the Gases," "On Dr. Medlock's Process of Filtering and Purifying Water," "The Gyroscope and Rotary Motion," "Note on Strychnine," "Chemistry in its Relation to the other Sciences," "Suggestions for a New System of Chemical Nomenclature," "Gaseous Exhalations and Miasmata as Causes of Nuisance and Disease," "Progressive Changes of Form in Rotating Spheroids," "High Tides and Colliery Explosions," "A Law of Elliptic Motion," &c.

Mr. Hamilton had the satisfaction, in the closing years of his life, of witnessing the adoption, in modified form, by the Liverpool Council of Education and the Liverpool School Board, of that system of scientific education which he had at the beginning of his career as a teacher regarded as a necessary part of primary instruction; and in the department of higher education his later years were cheered by the establishment of University College, Liverpool.

From his earliest years Mr. Hamilton had advanced views on education, but he was no theorist. In the face of opposition and many difficulties, he practised what he believed. Others have now entered into his labours, and the cause is making rapid progress. Mr. Hamilton's courteous manners, his devotion to duty, and his high intellectual attainments won for him the affection and esteem of all who knew him.

He was elected a Fellow of this Society January 12, 1855.

Robert James Mann was born in Norwich in January 1817. At an early age he evinced a great love of, and aptitude for, physical science. Botany was his first pursuit, and, while still a student, he published an excellent list of the flowering plants of the Norfolk district.

He was educated for the medical profession, and studied at University College. He took the M.R.C.S. and L.S.A. degrees in 1840, and for some years practised in Norfolk, continuing his scientific pursuits, and beginning to occupy himself with literary undertakings also. It was during this time that he published his first book, "The Planetary and Stellar Universe."

In 1853 domestic circumstances, connected with health, caused him partially to abandon the practice of his profession. In 1854 he became an M.D. of St. Andrews, and about this time was employed in assisting his old teacher and attached friend, Dr. C. J. B. Williams, in the revision and publication of his "Principles of Medicine," assistance, the value of which was generously acknowledged in the work itself, and again in the much more recently published "Memorials of Life and Work" of that eminent physician.

In 1857, on the invitation of Bishop Colenso, Dr. Mann left England for Natal, where he resided nine years, during seven of which he was Superintendent of Education for that colony; an office established by the then Governor, Mr. (now Sir John)

Scott, to which he received the first appointment. In this capacity he succeeded, working against great difficulties, in starting elementary schools for both the English and Dutch inhabitants, and ultimately in assisting those for the native population also. This, no doubt, is a noteworthy achievement in his life, and its value and the way in which it was accomplished have, since his death, been borne testimony to in the *Natal Mercury* of September 14 of last year, in the following words:—"For several years he gave up his time most unsparingly to a task which to him was a labour of love, and the measure of his personal success may be gauged by the extent to which his work suffered when his own part in it was withdrawn."

From his first arrival in Natal he also carried out day by day and recorded meteorological observations, the tabulated results of which are in the hands of the Meteorological Office. After his return to England he twice served as President of the Meteorological Society. While still in Natal he was, besides, the referee of the whole colony on all matters connected with science.

In 1862 he was the chief organiser of the exhibits the colony contributed to the great exhibition of that year, and he arranged and carried out a preliminary exhibition in Durban.

He returned from Natal in 1866, in consequence of receiving a special appointment from the Legislative Council to inaugurate a scheme of Government emigration to the colony. This he held for four years, during which, besides undertaking all the arduous work of his official position, he took charge of the arrangements of the Natal exhibits in the Paris Exhibition of 1867. He laboured gratuitously in promoting emigration to Natal for two years after his appointment as agent was withdrawn.

From about that time he ceased to have any special connection with the colony, and for the rest of his life devoted himself to the scientific and literary pursuits which had ever been congenial and delightful to him.

Of all the sciences which early engaged his attention and became subjects of study none excited so profound an interest or kept so permanent a hold upon his regard as that of astronomy. All through his life it was the one which he would have desired, had circumstances permitted, to make his chief pursuit and occupation. His first work was entitled "The Planetary and Stellar Universe." He was prompted to write it solely by his own profound sense and fervid appreciation of the grandeur and beauty of the subject of which it treated. This was followed, in 1850, by a smaller work on "The Achievements of Sidereal Astronomy in the middle of the Nineteenth Century." Later on he published "A Guide to Astronomical Science." He also furnished to *Chambers's Repository* a "History of the Moon."

Dr. Mann was for many years on the staff of the *Edinburgh Review*, and the admirable articles which he contributed to it on astronomical subjects are well known. His last piece of literary

work, indeed, was an article on "The Recent Progress of Astronomy," which appeared in the number for April of last year.

He was a popular and prolific writer, and was a frequent contributor to several magazines and reviews. The protection of buildings from lightning was a subject on which he wrote a good deal, and for which he did much valuable work.

In 1874 he was appointed Secretary to the African Section of the Society of Arts; a post he only resigned in consequence of failing health at the completion of the last session of the society.

For four years he served as one of the Board of Visitors of the Royal Institution, of which he became a member in 1876, subsequently being elected on the Council.

In 1878 he was elected a Fellow of the Royal College of Surgeons. Dr. Mann was well known in scientific circles, and for many years he was a member of the Astronomical, Meteorological, Geographical, and Photographic Societies.

From first to last he was a most active and indefatigable worker, and his end was probably hastened by his being, during the last four months of his life, when already in failing health, busily engaged in preparing and bringing out the catalogue of the Natal Court at the Colonial and Indian Exhibition. He was at the Natal Court engaged in this last work only three days before being suddenly struck down by paralysis, which terminated fatally two days afterwards, on August 4. He was buried at Kensal Green Cemetery.

He was elected a Fellow of the Society March 9, 1855.

James Pearson, M.A., vicar of Fleetwood, was born at Preston, Lancashire, and received his education there, up to the period of becoming an undergraduate of Cambridge University, first with Mr. Abbott, a highly reputed private schoolmaster of fifty years since, and afterwards at the Grammar School, chiefly under the mastership of the Rev. G. Nun Smith, an excellent teacher and proficient scholar. Here the foundation was laid for the distinguished college honours afterwards gained by the pupil. Whilst at the grammar school he took the second place for several years, and finally was bracketed as equal with the first, the two entering together upon their university career. Mr. Pearson came out as a first class in the examinations of his year at Trinity College, was subsequently rewarded with a scholarship, and graduated in the high position of fifteenth wrangler in 1848. After two years of further residence he accepted the curacy of the rural parish of Scarisbrick, near Ormskirk, a position, it may well be allowed, not very congenial to a man of his antecedents and abilities, and he resigned it to accept the dual appointment of rector of St. Edmund's and mathematical master of the King Edward the Sixth Grammar School at Norwich. After retaining this for about four years he was chosen one of the mathematical professors in the Royal Military College, Sandhurst. Either a longing to live near the

scenes of his childhood or a preference for parochial work, probably both combined, led him to forego this advantageous position for a second edition of the life of a country clergyman at Altcar, near Liverpool, a presentation of the Earl of Sefton. The population was a scattered one of three hundred souls, and the care and companionship of these was scarcely adequate to keep up the mental calibre in a man like Mr. Pearson, who was always full, even to excitement, of scientific instincts. Here, however, he found one or two congenial spirits and kindred tastes, whose friendship he held dear to the end of his days. Another change yet awaited him, and in 1862 he went to Workington as vicar of St. John's in that town, and remained nine years, quitting it in 1871 to go to Fleetwood. At Workington he was greatly appreciated both as a teacher and a preacher, and this appreciation was manifested in a high degree by a handsome testimonial presented on his leaving, and more handsomely impressed by the testimony to his worth in the words which accompanied the presentation.

His scientific researches, besides astronomy, went in the direction of the study of the tides, and on this subject he was a very frequent and constant contributor to scientific papers. His system of tide computation was adopted by the Admiralty for this coast, and he designed and had erected on the pier at Fleetwood a novel and ingenious contrivance for registering the height of the tides and testing his calculations, which were always found to be very accurate. He designed several novel contrivances in connection with this subject, one of which has been for some time erected on the Blackpool Pier and another at Fleetwood. It consists of a dial, which is set each day and points to the height of the tide at all hours during that day, both ebb and flow. He also published a Treatise on the Tides in 1881, which was hailed with much approval by many astronomers of the day, and very soon became scarce. Several works of a minor character on this and kindred subjects proceeded at different periods from his pen, all denoting the enthusiasm of the author for his favourite studies.

Mr. Pearson died on April 8, 1886, after a lingering and painful illness.

He was elected a Fellow of the Society April 10, 1874.

Admiral Sir Charles Frederick Alexander Shadwell, K.C.B., F.R.S., was born on January 31, 1814, and was the fourth son of the late Right Hon. Sir Lancelot Shadwell, Vice-Chancellor of England. He entered the navy May 3, 1827, from the Royal Naval College, and passed his examination in 1833. On June 28, 1838, he obtained his lieutenant's commission, and was appointed in the following July to the *Castor*, Captain Edward Collier, with whom he served on the coast of Syria in 1840, and assisted at the operations against Caiffa, Jaffa, Tsour, and St. Jean d'Acre. His next appointment was

as first lieutenant of the *Fly*, in the East Indies, from December 1841 until June 1846, when he was promoted to be commander. In February 1850 he commanded the *Sphynx*, for service in the East Indies, and held this command through the Burmese War of 1851–1853, for his services in which he was on February 7, 1853, promoted to post rank, was gazetted to the Order of the Bath, and received the Burmese war medal with clasp. His next appointment was, in August 1856, to the *Highflyer*, which he commanded in the last war with China, taking part in the operations in the Canton River and in the capture of Canton, and being wounded in the attack on the forts at the mouth of the Peiho River in July 1859. For his services on this occasion Captain Shadwell was mentioned in despatches for "his valuable assistance." After the China War he was appointed to the *Aboukir*, which he commanded in the Channel and North America and West Indies in 1861 and 1862. His next appointment was that of flag-captain, in the *Hastings*, to Rear-Admiral Sir Lewis F. Jones at Queenstown, which he held till June 1864, when he was made Captain Superintendent of the Royal Haslar Hospital and of the Royal Clarence Victualling Yard. In this post he remained till he became Rear-Admiral in January 1869, vacating at the same time his appointment as Naval Aide-de-Camp to the Queen, which he had received in March 1866. He was commander-in-chief on the China station from 1871–1874. In 1873 he was gazetted a Knight Commander of the Bath, and in 1877 received the flag officers' pension for meritorious service. His last appointment was that of President of the Royal Naval College at Greenwich, which post he held from March 1878 till March 1881. He died at Meadowbank, Melksham, Wilts, on March 1, 1886.

In the year 1861 Sir Charles F. A. Shadwell was elected a Fellow of the Royal Society. He was the author of the following works :—"Formulæ of Navigation and Nautical Astronomy" (for the use of naval officers and students of nautical astronomy), "Tables for Facilitating the Approximate Prediction of Occultations and Eclipses," "Tables for Facilitating the Determination of the Latitude and Time at Sea by Observations of the Stars," "Tables for Facilitating the Reduction of Lunar Observations," "Notes on the Management of Chronometers and the Measurement of Meridian Distances," "Notes on Interpolation, Mathematical and Practical" (intended to form Ch. VI. of a work on navigation and nautical astronomy, which the author left incomplete at his death).

He was elected a Fellow of this Society on January 8, 1847.

David Smith was born at Selby, Yorkshire, in September 1821. He left school at the age of fourteen, and for about eighteen months was employed as a railway clerk, after which he was apprenticed to a carpenter and builder, and also studied for an architect and surveyor. In the year 1842 he went to

America, where he remained two years, travelling through the United States, and also the backwoods, collecting specimens of natural history, and at the same time earning his living by his trade of a carpenter, &c. Upon his return to England he went to Birmingham, and there spent the remainder of his life, the last twenty years of which he practised as an architect and surveyor. Always of a profoundly studious turn of mind, he early became deeply interested in the science of astronomy, and soon made himself conversant with that and other kindred physical sciences.

His meteorological observations were daily recorded, and published periodically in the local newspapers. In 1865 he was elected a member of the British Meteorological Society, and he had the honour of reading a paper before the British Association, at their meeting in Birmingham in 1865, on "The Meteorology of Birmingham," being the results of personal observations extending over a period of twelve years, viz. from 1853 to 1864 inclusive.

He was indefatigable in his efforts to spread scientific and useful knowledge amongst those around him, and by popular lectures, and the formation of science classes, he laid the foundation of that well-known and valuable establishment, the Bloomsbury Institution, where educational work is still carried on in connection with other useful agencies. As a public lecturer on astronomy, geology, meteorology, physiology, and various other subjects, Mr. Smith was deservedly popular, and his removal has caused a gap which it will be difficult to fill up.

His decease occurred after a short illness on December 23, 1885, and his loss is deeply felt and regretted by all who were connected with him.

He was elected a Fellow of this Society on June 13, 1862.

Edwin Story was educated at Shrewsbury School and St. John's College, Cambridge. He was a great lover of science, and became a member of the Linnæan, Geological, Historical, and Royal Geographical Societies. His favourite recreation from sterner mental study was the indulgence of poetical composition, particularly of classical poetry, in which he delighted and excelled.

Mr. Story was essentially of a retiring disposition; he led a studious and well-spent life, which was terminated by paralysis on February 1, 1886.

He was elected a Fellow of this Society November 8, 1867.

Charles George Talmage was born at Greenwich on November 12, 1840. He was educated at a proprietary school there, and afterwards studied mathematics under a private tutor.

Mr. Talmage commenced his astronomical career in the year 1856, at the Royal Observatory, Greenwich, where he remained for about four years. In 1860 he joined Mr. Hind as assistant

at Mr. Bishop's Observatory in the Regent's Park. At this time Mr. Talmage was in very delicate health, and it was considered necessary for him to sojourn in a warmer climate; he therefore was compelled to leave Mr. Bishop's Observatory, and subsequently accepted an appointment as private secretary to the late Mr. R. Coventry, who was then residing at Nice. There Mr. Talmage devoted himself to double star observations, and undertook a re-examination of Admiral Smyth's Bedford Catalogue. Four years' residence in the south of France so far restored him to health as to enable him to return to England, where he again joined Mr. Hind for a short time at the Observatory, which Mr. Bishop had removed from the Regent's Park to Twickenham.

In 1865 Mr. Talmage was appointed Director of the private Observatory of Mr. J. Gurney Barclay at Leyton, which appointment he held up to the time of his death. Here he devoted the fine 10-inch Cooke refractor almost exclusively to double star work. Most of his excellent observations have been published in the volumes of the "Leyton Astronomical Observations," and others will be found in the volumes of the *Monthly Notices*. (It is to be regretted that with Mr. Talmage's death the work of the Leyton Observatory has closed, as Mr. Barclay has since then presented the large equatoreal to the Radcliffe Observatory, Oxford, and the Transit circle to the Oxford University Observatory.)

In 1870 Mr. Talmage went out in the "Urgent" to Gibraltar to observe the Total Solar Eclipse of that year, his duty being to take angular measurements of *Saturn* if seen through the corona, but the unpropitious weather on the day of the eclipse prevented any observation being made. In 1882 he was appointed by the Government as officer in charge of the West Indian expedition for observing the Transit of *Venus*. He was located at Barbadoes, in company with Lieut. Thomson, R.A., where he was fortunate in securing good observations of all contacts both at ingress and egress.

Mr. Talmage was for many years a member of the British Association, and regularly attended their meetings. Besides being an able microscopist, he had no mean knowledge of medicine and botany.

In the locality in which he lived Mr. Talmage was both respected and beloved. His hearty, genial, and kind disposition made him numerous friends whithersoever he went. Ever ready to afford to others all the help that was in his power, and with a happy ungrudging manner which made him deeply esteemed, it is no wonder that his untimely death has caused a wide-spread feeling of regret among those who knew him. He was taken seriously ill on February 23, 1886, and, after much suffering, died on March 20.

A memorial to him has been erected by his many friends in the church of St. Michael and All Angels, Walthamstow.

He was elected a Fellow of the Society Dec. 11, 1863.

William Tomlinson, Junior, was born at York about forty-five years ago, where he received his education at St. Peter's School, in which his father held the position of mathematical master. About twenty years ago he went out to New Zealand to Bishop Abraham, of Wellington, with the intention of taking holy orders. From Wellington he proceeded to Wanganui, and there, feeling that the teaching profession was the vocation of his life, he entered upon its duties with all the zeal of his enthusiastic nature as assistant master in the school conducted by Mr. Goodwin. While in Wanganui it may be mentioned that the Maori War was raging, and during that troublous time Mr. Tomlinson belonged to a local cavalry corps, took part in some engagements with the natives, and was rewarded with a New Zealand war medal. Subsequently he was appointed to the position of assistant master at the Nelson College, where he remained until 1873, when he received the appointment at the Auckland College and Grammar School, which he held at the time of his death. During his residence at Nelson he married a daughter of the late Mr. Samuel Kingdon. Mr. Tomlinson was of very scholarly habits, and in 1883, notwithstanding the demands upon his time by his professional duties, he succeeded in obtaining the B.A. degree in connection with the New Zealand University. He was a diligent student of astronomy himself, and encouraged the study of it in no small degree in others. He took a creditable degree in the University of New Zealand, in which astronomy was a subject of examination, and he gained considerable repute by his writings on educational matters, and was also distinguished as a public teacher and private coach; but his onerous duties, and the exigencies of a large family, did not allow him to carry out the practical views which his sound mathematical knowledge would have enabled him to do; but at the time of his death he was looking forward with a lively hope to a time when more leisure, less onerous duties, and easier circumstances would have enabled him to do good service to practical astronomy.

His success as a teacher must be attributed to his enthusiasm for his profession. He always felt that the imparting of knowledge was comparatively a small part of a schoolmaster's work, and that the development of a manly and upright character in each of his pupils was his highest aim. In fact, he wished to make them gentlemen in the true sense of the term, and his own demeanour and bearing towards his pupils were the most powerful factors in producing this result. His genial disposition and active habits led him to take the deepest interest in the doings of his pupils in the playground, and he naturally became a great favourite with them. His interest in his pupils did not cease when they left school to enter upon business pursuits, and he always manifested a great concern for their welfare, and was ever ready to assist those who desired to further pursue their scholastic studies.

Mr. Tomlinson's death took place under exceptionally lamentable circumstances. On the morning of January 21, 1886, he went out with a double-barrelled gun, intending to shoot gulls. He was accompanied by his eldest son, aged eleven, and in climbing up a hill in the Wakapuaka Road, he slipped, when the gun exploded and the shot from the charge went through his heart. He has left to mourn his loss a widow and a family of five children.

He was elected a Fellow of the Society April 9, 1873.

Professor Theodor von Oppolzer, the only son of the celebrated physician Dr. Johann von Oppolzer, was born at Prague, October 26, 1841. His early years were spent at Leipzig, whence, while yet in his childhood, he moved to Vienna, as his father had been appointed professor at the university of that city. Here he studied physics, but his abilities and great predilection for mathematics induced him to devote all his spare time to the study of natural philosophy. In these studies he was aided by Dr. E. Weiss, the present Director of the Vienna Observatory, who soon recognised his eminent talents for Astronomy, and encouraged him to devote his life to that science. Oppolzer, who was possessed of independent means, sufficient to remove all necessity for seeking immediate employment, therefore constructed a well-appointed observatory after he had taken the degree of a Doctor of Physics. At this observatory he observed asteroids and comets during the years 1862 to 1872 with great zeal, and his computations of the orbits of such bodies were the first papers by which he introduced himself to the astronomical world. For such work he was especially qualified by the quickness and certainty with which he conducted extended numerical computations. He published numerous papers on this subject.

He also published all his valuable theoretical researches in this branch of Astronomy in an excellent "Lehrbuch zur Bahnbestimmung der Kometen und Planeten," of which the first volume appeared 1870; and in a second, totally revised and much enlarged edition, 1882. The second volume was published in 1880. In this classic work the author has in fact reconstructed on a more comprehensive plan the *Theoria Motus* of Gauss. The theories upon which the calculation of the orbits of comets and planets depend are discussed so fully and exhaustively, that the work forms, indeed, a Treatise on Astronomy, "not only useful to the practical Astronomer, but of the highest value to the Mathematician who desires to know the exact manner in which the dynamical formulæ he is acquainted with are actually applied in practice to the calculation of orbits." This most important work has been recently translated into French by Prof. Ernest Pasquier, of Louvain.

In the year 1873 Prof. Oppolzer was entrusted by the Austrian Government with the astronomical work for the *Europäische Gradmessung*. In this position, which he held till his death,

being in his last years chairman of the Austrian Commission of the *Europäische Gradmessung*, he showed an extraordinary ability as an organiser, and executed a long series of telegraphic longitude operations between various cities of Austria amongst each other, and with the capitals of other countries. For many weeks in the summer of 1876 operations were undertaken at the Royal Observatory, Greenwich, by Professor Oppolzer's assistants for the purpose of making the time observations and telegraphic observations necessary for determining the longitudes of Vienna and Berlin, connected also in some measure with Munich and Paris. All the observations for this very extensive work are finished, but unfortunately the reductions are not very far advanced. In connection with these investigations he also conducted a series of pendulum experiments for determining the intensity of gravity at Vienna, and he made a very interesting and important study of the vibrations of the stand of the pendulum and their influence on the time of its oscillation. But here also his very premature death prevented him from discussing more than a small part of these extremely delicate researches, for which he devised special methods of observation and reduction.

In the year 1881 Oppolzer published "Syzygien-Tafeln für den Mond," which were intended to supply a simple and convenient means of finding very approximately the time of New and Full Moon, particularly in the case of an ecliptic syzygy, and of calculating all the circumstances of an eclipse without the necessity of having recourse to the Solar and Lunar Tables.

But the most important work undertaken by Oppolzer is his "Canon der Finsternisse" [Table of eclipses], which will be found to be an invaluable basis for all historical researches connected with solar eclipses, and will form an enduring monument of the power of its author.

This masterly paper contains not only the elements of eclipses of the Sun, but also of those of the Moon from 1207 B.C. to 2162 A.D. The elements are given for all the eclipses partial and central occurring during this period of time.

The tables furnish the computations of 8,000 Solar Eclipses, of which about 2,220 are total, 355 annular and total, 2,605 annular, and 2,820 partial.

Of the Moon, 5,200 eclipses are computed; for which the tables give not only the date, but also the magnitude, the time of the middle of the eclipse, and the geographical position of the point on the earth where the Moon at that moment is at the zenith.

Appended to the work are 160 charts, in which is laid down the central line of all Solar Eclipses visible in the northern hemisphere, and as far as 30° south latitude. Partial eclipses of the Sun, and those which are central only in regions more south than 30° are not mapped.

The work forms vol. lii. of the *Memoirs of the Imperial Academy of Sciences* at Vienna.

This noble undertaking Oppolzer was only just able to bring to a conclusion, for it was but a few hours before his death that he read the last proof-sheets of it.

Besides all this, Oppolzer was engaged during the last years of his life in researches on planetary disturbances, especially on the theory of the motion of the Moon, on astronomical refractions, and on the resisting medium, &c.

From this brief record of his more important researches it will readily be understood that his life was one of constant work, and that he was enabled to perform all he did only by an indefatigable diligence, a very remarkable power of memory, quickness of perception, and intuitive grasp of whatever he studied.

Von Oppolzer was appointed in 1876 Professor of Astronomy at the University of Vienna, and received besides this, various other distinctions from the Austrian Government and several foreign sovereigns. He was also Member of the Imperial Academy of Sciences at Vienna, Honorary Member of the Royal Academy at Munich, Correspondent of the Institute of France, and Fellow of many other scientific bodies. He was elected an Associate of the Royal Astronomical Society on Jan. 9, 1874.

In the middle of November 1886 Oppolzer returned to Vienna somewhat ill, after attending the Paris International Conference on Weights and Measures, and the meeting of the Permanent Commission of the *Europäische Gradmessung* at Berlin. No one would have considered, however, from his appearance, that his end was so near. At first his illness was thought to be a kind of malaria, but it very soon proved a serious disease of the heart, of which he suddenly died, on the morning of December 26, at the early age of 45 years.

E. W.

Proceedings of Observatories.

The following Reports of the proceedings of Observatories during the past year have been received by the Council from the Directors of the several Observatories, who are alone responsible for the same.

Royal Observatory, Greenwich.

During the past year the meridian work at this Observatory has been sensibly increased by the efforts made to complete the forthcoming Ten Year Catalogue of Stars (1877–1886) as far as possible, both by securing places of nearly all stars down to the sixth magnitude inclusive, not observed at Greenwich since 1860, and by obtaining at least three observations of each star. Thus the total number of meridian transits for 1886 is 6,417, and of meridian zenith distances 6,219; the numbers for the month of December alone, when special efforts were made, being 1,133 and 1,093 respectively. The number of stars observed during 1886 is 1,666. At the same time the stellar work has not been allowed to interfere with the regular observations of Sun, Moon, and planets, and the general work in other respects has been rather heavier than in previous years. The proper motions in use have been carefully revised and compared with those of Auwers; and, in the case of clock stars, a further comparison has been made with the last ten years of Greenwich observations, from which it is clear that Auwers' proper motions may be advantageously adopted throughout. They will accordingly be used regularly from January 1, 1887, and also in the formation of the Ten Year Catalogue. As a preliminary to this, the application of proper motion for fraction of the year has been thoroughly examined for every observation in the period 1877–1886, and corrections applied where, as occasionally happened, different proper motions had been used in the same year. Preparations have been made to apply corrections for reduction to Auwers' proper motions, and for reduction to the same R−D correction throughout in the computations for the Ten Year Catalogue.

A considerable amount of information has been obtained as regards personality in observation, both as depending upon

direction of measurement or motion, and on the differences between the chronographic and the eye-and-ear method of observing. The reversion prism has been used to observe about 200 transits of clock stars and 200 of polar stars with the transit-circle, and about 550 of the Moon and stars with the altazimuth, more than 200 of these latter being observed by eye and ear. As a general result, it appears that there is in no case any sensible personality depending on the direction of measurement, and that the personality depending on the direction of motion is in every instance very small for clock stars, and insensible for slow-moving polar stars. For the regular observers the eye-and-ear personal equations differ but little from the chronographic, except in one instance, where the difference amounts to as much as $0^s.6$. From observations made with the personal equation machine, which has been found to work satisfactorily, and to give results in accordance with those deduced from observations of clock stars, it would appear that all the observers observe too late. Further observations are, however, required to determine the absolute personal equations with certainty. With a view to obtaining a register of the end as well as the beginning of the contacts made by the personal equation machine, a small chronograph, by Krille, made many years ago for mechanical registration, is being adapted by Messrs. E. Dent & Co. to electric registration of make-and-break contacts.

The mean error in R.A. of Hansen's Lunar Tables with Prof. Newcomb's corrections is $+0^s.029$ for the year 1886, as deduced from ninety-six observations with the transit-circle; for the years 1883, 1884, 1885, the corresponding quantities were respectively $+0^s.032$, $+0^s.021$, and $+0^s.028$.

Four determinations of flexure of the transit-circle in 1886 gave results $+0''.15$, $+0''.42$, $-0''.16$, and $+0''.13$.

The apparent correction to the nadir observation, deduced from reflexion observations of stars in 1886, is $-0''.09$, the results for individual months showing considerable fluctuations. In comparing this with results for previous years, it is to be remarked that new steel screws were applied to the microscope micrometers on January 1, 1886. It is considered that no correction is now required to the nadir observation.

Experiments on the effect of the limitation of aperture when observations are taken through the central cube of the transit-circle having led to the suspicion that the object-glasses of the collimators might be defective, they have been examined by Mr. Simms, who has reported that they are excellent.

The altazimuth observations of the Moon in the first and last quarters have been regularly continued as before.

Further additions have been made to the Lassell Equatorial, with a view to adapting it to stellar photography. With this object the Corbett Refractor of $6\frac{1}{2}$ inches aperture has been mounted on the cradle of the Lassell telescope, so that the position of the compound instrument can be very conveniently

watched by an observer. Slow motion in R.A. with differential wheels, and an improved clamp and slow motion in N.P.D. are being added. A circular camera to carry plates of $8\frac{1}{4}$ inches diameter has been mounted at the principal focus, but no photographs have yet been taken.

Progress has been made in the construction of the new 28-inch refractor. A satisfactory flint-glass disc has been produced by Messrs. Chance, and M. Feil of Paris has undertaken to supply the crown disc. The details of the special tube have been finally settled, and Mr. Grubb is engaged on its construction.

Comet *d* 1885 (Fabry) has been observed on five nights with one or other of the equatorials; Comet *e* 1885 (Barnard) on nine nights; Comet *a* 1886 (Brooks) on six nights, and Comet *f* 1886 (Barnard) on twelve nights. Twenty-four occultations of stars by the Moon have been observed, in five cases by two observers, in one by three observers, and in two by four observers; and forty phenomena of *Jupiter's* satellites, with one or other of the equatorials.

Owing to the pressure of the Sun-spot work and the absence of Mr. Maunder in the summer for observation of the solar eclipse in Grenada, the chromosphere has only been examined on eight days. With respect to measures of the displacements of lines in stellar spectra, 283 comparisons of the F line, and 30 of the *b* lines have been made, the number of stars examined being 54. The displacements of the *b* and F lines in the spectra of *Venus* and *Mars* have also been measured, 20 observations having been made on *Venus* and 19 on *Mars*; while 94 comparisons of the *b* or F lines in the spectrum of the Moon or of the sky have been made for general check on the accuracy of the results; and 5 measures have been obtained of the relative motion of the limbs of *Jupiter*.

The spectra of Mr. Gore's new star in Orion, of 51 Schjellerup, and of Comets *e* 1885 (Barnard) and *f* 1886 (Barnard), have also been examined. Photographs of the Sun, 420 in all, have been taken on 209 days, and these have been supplemented by photographs taken at Dehra Dûn, in India, and at the Royal Alfred Observatory, in Mauritius; so that in the year ending Oct. 31, 1886, there are only 5 days on which no photograph is as yet available for measurement. A very marked decrease in the number of spots is noticeable in 1886, especially in the last six months; indeed, since the middle of September, the Sun has been almost free from spots.

The magnetical and meteorological observations have been carried on on the same lines as in previous years, and the observations of the principal meteor-showers have been continued.

The arrangements for trials of chronometers and deck watches have engaged much attention during the past year, and the business connected with chronometers generally has pressed heavily on the Observatory. One of the clocks returned from

the Transit of *Venus* Expedition (1874), has been fitted up at Devonport, under Capt. Wharton's directions, to give time signals to the port. This clock is adapted to give hourly signals (by the collapsing of a cone or drum), and is corrected daily by the help of a time signal from Greenwich at 10 A.M., which automatically starts an auxiliary seconds' pendulum, suspended freely just behind the clock pendulum. The attendant then accelerates or retards his clock pendulum by electro-magnetic action, so as to synchronize it with the free pendulum, indicating Greenwich mean time. Preliminary trials of the clock were made at Greenwich last summer, and it has been in successful action since December 1, a return-signal to Greenwich, sent automatically by the Devonport clock at $1^h\ 0^m\ 39^s$ P.M., giving evidence of the accuracy with which the clock has been corrected.

The volume of Greenwich Observations for 1884, and the separate copies of results, were distributed last October, and the printing of the volume for 1885 is nearly complete. In an appendix to the Greenwich Observations, is given a series of diagrams representing the diurnal change in magnitude and direction of the magnetic horizontal force for each month of the years 1841 to 1876, by Sir G. B. Airy, K.C.B., late Astronomer Royal.

Two members of the staff of this Observatory, Mr. Turner and Mr. Maunder, took part in the expedition to Grenada, West Indies, to observe the total solar eclipse of 1886, August 29.

Armagh Observatory.

The micrometrical observations of nebulæ have been continued with the 10-inch refractor, but during the greater part of the year the weather was very unfavourable for faint objects. The nebulæ on the working list are chiefly such as have not yet been observed with wire micrometers. A great deal of time has been spent in reducing to the epoch of 1860 all the positions of nebulæ published during the last ten years, with a view to the compilation of a new General Catalogue of nebulæ and clusters.

The Second Armagh Catalogue of 3,300 stars was distributed in August last.

Cambridge Observatory.

The zone stars are nearly all now observed, and the reductions are steadily progressing.

The total number of observations of stars made with the Meridian Circle during the year is 2,252; of these 651 were of clock stars, 70 of *Polaris* above the pole, involving 152 circle

readings, and the same number below the pole with 169 circle readings; the remaining 1,461 observations were of zone stars.

The Nadir point and level were observed 202 times, the line of collimation 200 times.

The entire number of observations of zone stars, since the commencement, now amounts to 43,576.

The Mean Right Ascensions at the epoch (1875·0) are determined up to July 12, 1877; the Mean Right Ascensions January 1·0 of each year up to the end of 1881; and the True Right Ascensions to September 30, 1886.

The North Polar Distances are reduced to the epoch up to March 16, 1878; the Mean North Polar Distances for January 1·0 of each year to the end of 1881; and the True to November 25, 1886.

511 observations of standard stars made by Mr. Graham in 1885 give $+0''\cdot55$ for the mean reduction to the standard Berlin places in North Polar Distance, without making any allowance for flexure or errors of division; 82 observations by Miss Walker, nearly all taken by daylight, gave $+1''\cdot18$. The North Polar Distance was, as in former years, deduced from the observed Nadir point, and the assumed colatitude 37° 47′ 8″·4.

60 observations of *Polaris* above pole, corrected for flexure and errors of division give, for reduction to Berlin N.P.D., $+0''\cdot45$; while 59 observations below pole, similarly corrected, give $-0''\cdot33$. These give for the reduction of Cambridge to Berlin N.P.D. for *Polaris* $+0''\cdot06$, and for correction of assumed colatitude $+0''\cdot39$.

It may be interesting to compare the colatitudes obtained from *Polaris* and observed Nadir Point for the last eight years.

1878 . .	37°	47′	8″·86
1879 . .			8·98
1880 . .			8·815
1881 . .			8·755
1882 . .			8·85
1883 . .			8·825
1884 . .			8·96
1885 . .			8·79
Mean . .	37	47	8·854

Polaris was observed directly and by reflection on April 8; the coefficient of correction for level thence deduced is $b=-0^s\cdot337$, the coefficient obtained on the same day by means of the collimators and the reflection of the wires is $b=-0^s\cdot335$; the unit in each case being 15″ of arc.

On May 12, 1886, we furnished Dr. Gustaf Ericsson, of Upsala, with the places for 1875·0 of four of our zone stars which had

been compared with the Comet 1863 III., and on November 24 we likewise supplied Mr. Bidschof of Vienna with the places for 1875·0 of nine of the zone stars which had been compared with one or other of the Comets 1848 I. and 1849 III.

Dunsink Observatory.

During the early part of the year the Meridian Circle was employed, along with the chronograph, for observing stars with large proper motion, taken chiefly from the sources mentioned in last year's Report. From the middle of February, however, up till September, the observation of these stars was frequently interrupted for the purpose of completing the list of southern stars referred to in former Reports. The work of filling up the gaps still remaining in this list necessarily occasioned long delays at the telescope, so that the number of observations this year will compare unfavourably with that in former years.

The latter months of the year, from September to December, were almost entirely occupied with the work of preparing for the press the Sixth Part of the Dunsink Observations, which will contain the observations of the southern stars which were commenced by Dr. Dreyer in 1882. This work is now in the hands of the printer, and will shortly be published.

The number of Right Ascensions observed was 506, and of Declinations 295, besides observations of standard stars for the time service to Dublin.

In addition to the usual observations of Right Ascension and Declination, a large number of measures were made in January, February, and December for determining the periodic errors of the microscope screws. The corrections were found to be of the same general character, but smaller than at the last determination.

For the purpose of determining the difference of the radii of the pivots of the Meridian Circle a large number of levellings have been made in both positions of the instrument. They show that the correction for this irregularity is small, but its exact value has not been deduced, as the series of observations is not yet complete.

The results of the observations of the occultation of *Aldebaran* on January 16 which were made at this Observatory have been published in the *Monthly Notices* for February.

Records of the velocity and direction of the wind have been taken as usual throughout the year.

Royal Observatory, Edinburgh.

Through the past twelve months, transit observations for sidereal time, and electrical exhibitions of mean solar time computed for Greenwich, and given to the public by means of

time-ball, time-gun, and controlled clocks, have been kept up daily.

The bi-diurnal meteorological observations at 55 stations of the Scottish Meteorological Society have been computed, condensed, and described, partly every month and wholly every quarter, for the Registrar-General of Births, Deaths, &c., in Scotland, in whose printed returns for months and quarters they have accordingly appeared.

During the past autumn the printing of the "Edinburgh Catalogue, Discussion, and Ephemeris of Stars" was completed, published, and distributed in the usual manner as one thick volume, numbered XV. of the Observatory series; and MSS. chiefly spectroscopic are now being prepared for a proposed volume XVI.

A paper has been also written by the Astronomer descriptive of his proposed new method for finishing the Equatorial of the Edinburgh Observatory; but it is kept in abeyance until the scheme of the Government Committee of 1879 shall have been either carried out or given up by those charged with its execution.

The Kew Observatory of the Royal Society, Richmond.

The Sun-spots were delineated and numbered after Schwabe's method, as usual, on 169 days during the past year.

Three hundred and nine observations of solar and sixty-one of sidereal transits have been taken, for the purpose of keeping correct local time at the Observatory, and the clocks and chronometers have also been compared daily.

At the request of General Walker, F.R.S., certain experiments were made with the view of determining the stability of the Experimental House as a site for pendulum operations. These having proved that building unsuitable, a wooden erection of convenient dimensions has been constructed, at the desire of the Pendulum Committee of the Royal Society, in the lower South Hall of the Observatory, on the spot occupied in 1873 by Captain Heaviside, R.E., when experimenting with the Russian pendulum.

In this room the Indian Pendulum Apparatus, recently returned by Professor Pierce from the United States, has been erected, in order to repeat the observations made by Colonel Herschel, R.E., in 1881, Captain Heaviside in 1873, and Captain Basevi in 1865. Eventually, it is intended to convey the whole to Greenwich, and at the Royal Observatory another series of observations and experiments will be conducted.

The usual magnetical and meteorological observations and reductions, and also the verification of instruments, operations to which the attention of the Observatory is mainly directed, have been carried on as formerly.

Liverpool Observatory, Bidston, Birkenhead.

Careful attention has been given to transit observations of stars for the determination of clock errors. The two sidereal clocks have been compared daily with the normal mean-time clocks, and duplicate comparisons of all the chronometers with the latter have been made daily as heretofore. Greenwich mean time has been communicated to the Port daily, Sundays excepted, by means of the time-gun placed on the Morpeth Dock Pier-Head. No instance in which the gun has failed to fire has occurred during the past year, and the flash has in each case accurately indicated 1 P.M. as shown by the normal clock in the chronometer room. Two hundred and twenty-seven chronometers have been tested during the past year. When the test certificate shows the performance to be unsatisfactory, it is the general practice for the maker to examine and adjust the instrument, and return it to the Observatory to be re-tested. An important service is thus rendered to shipowners and ship-masters by preventing defective and imperfectly-adjusted chronometers being taken to sea. The records received during the past year of the performance at sea of the Pacific Steam Navigation Company's chronometers show that, using the rates corrected for temperature supplied from this Observatory, the average error of longitude by chronometer for an average voyage of 101 days was about four miles.

No alteration has been made in the meteorological work. No interruption has occurred in the records of the self-registering instruments and the daily, weekly, fortnightly, and monthly Reports have been furnished as in previous years.

Radcliffe Observatory, Oxford.

The following have been the subjects of observation during the year 1886:—

With the Transit Circle:—

1. Observations of stars to the seventh magnitude inclusive between 115° N.P.D. and the Equator.

2. Observations of the Moon, which are continued throughout the lunation, and regularly compared with the Right Ascensions and North Polar Distances of Hansen's Lunar Tables. Such comparisons have been generally discontinued at other Observatories; and these results, therefore, appear to have a special value in keeping distinctly before astronomers the extraordinary

character of the change between the results of observation and theory which took place about the year 1864. The mean error in longitude of Hansen's Tables has changed from $-1''\cdot61$ in the year 1863·5 to $+15''\cdot34$ in the year 1886·5, being at the average rate of $0''\cdot74$ per annum.

3. Observations of the Sun.
4. Reflexion observations of stars.

The following table gives the number of observations made during the year 1886:—

Transits, 2,812.
Circle observations, 2,663.

These totals include—

Observations of the Moon on 49 days.
Observations of the Sun on 76 days.
23 Reflexion observations of stars.
365 Determinations of Nadir point.
2 Durations of passage of the Moon's diameter.
2 Vertical diameters of the Moon.

With the extra-meridional instruments:—

13 observations of 9 occultations of stars by the Moon.

The volume for 1883 has been printed and distributed.

The volume for 1884 is being prepared for press.

The observations made in 1885 and 1886 are completely reduced.

A well-mounted Equatorial by Cooke with an exquisite object-glass of ten inches aperture has been presented to the Observatory by J. Gurney Barclay, Esq. The building for the reception of the instrument has been prepared from designs kindly furnished by Mr. Common, but the continuance of the late severe frost has delayed the arrival and mounting of the instrument.

Oxford University Observatory.

The work of this Observatory has been necessarily confined during the past year to a research as to whether the new process of Astronomical Photography is or is not practically applicable to the most delicate of astronomical investigations, such, for instance, as the determination of Stellar Parallax. The reply is unmistakably in the affirmative, inasmuch as the Parallax of 61^1 and 61^2 *Cygni* has been obtained in reference to no less than four comparison stars, with singularly accordant results. The preliminary particulars have been communicated to the Royal Society and the Royal Astronomical Society.

The attention of the Observatory staff has also been directed to the mounting, renovation, and electric lighting of the excellent Transit Circle presented to the Observatory by Mr. J. G. Barclay.

Temple Observatory, Rugby.

This Observatory has been opened on seventy-six evenings during the year, on most of which there has been the usual attendance of members of the School, when the usual instruction has been given.

Mr. Seabroke has given the whole of his spare time to the measurement of the motion of stars in the line of sight with the spectroscope on the Reflector, and 100 sets of measures have been made.

The results of the last few years have been reduced and lately brought before the notice of the Society.

Mr. Percy Smith has continued the work of measuring the position and distance of double stars, and has been doing clerical work in connection therewith. He has also arranged all our star forms for future re-observation.

Stonyhurst College Observatory.

The solar work continues to receive the same attention as in previous years. The Sun was observed on 235 days, and 224 drawings were made of the whole disk, including spots and faculæ.

Whenever the definition was particularly good the general surface of the Sun has been studied in conjunction with Janssen's excellent photographs, and continual change is seen everywhere.

The measures of the chromosphere and prominences have been more successful than in any other years, 101 complete observations and two partial ones being recorded.

The spectra of Sun-spots were examined on 21 days, and on six of these occasions spot bands were visible. The lines most widened this year were generally the ordinary solar lines, which was far from being the case during the maximum period.

A new class of solar observations has been added to the routine work this year, the direction of the flames of the chromosphere being noted with a wide tangential slit. As these observations require a very perfect sky, and are only made when the others are completed, they are entered only on 21 days.

Positions of the comets of Fabry, Brooks, Barnard, and

Finlay have been determined, and the usual watch kept for the phenomena of *Jupiter's* satellites and for lunar occultations.

In preparation for the total solar eclipse of August 29, a $5\frac{1}{2}$-inch object-glass by Alvan Clark and a powerful direct-vision spectroscope by Hilger were purchased by the college authorities.

Mr. Common's Observatory, Ealing.

The last year has been entirely devoted to the construction of the 5-foot reflector. The machine for grinding was completed in September, and great progress has been made with the mirror. Photography has been used to obtain permanent records of the state of the surface by using the reflected light from a pinhole (illuminated by a lamp), as in the system of testing used by Foucault. It is found that so small a quantity of light as can come through a hole ·004 inch placed at the centre of curvature can be photographed in a few seconds after reflection from the surface.

A series of photographs have been taken from the first rough polish to the present state, and will be continued.

The kind of mounting has been determined upon, and the heavy work put in hand. It is hoped that the whole may now be completed without further delay.

The telescope is to be devoted to photography, and the mounting has been designed to give the greatest amount of steadiness and perfection of movement.

The Earl of Crawford's Observatory, Dunecht.

Early in the year Dr. L. Becker concluded the determination of the latitude by prime vertical observations begun in 1885. This involved an exact examination of the pivots with the level, which proved particularly interesting, as it could be made in both the pairs of Y's with which the instrument is provided. The maximum error is $0''{\cdot}66$, corresponding to 0·00006 inch; but only a small fraction of this affects the telescope when near the zenith. The general figure of the axis comes out the same when rotated in the meridional bearings, as in those for the prime vertical. The observations are all reduced.

In the moonless nights of the autumn Dr. Becker turned the large aperture of the Transit Circle to account by observing nebulæ; in this way ninety-six places have been secured in seventeen nights. The bright nights were devoted to comparison stars and to a complete re-determination of the positions of the

Durchmusterung stars within 1° of the pole. This latter work is carried on with bright-field illumination. Observing was commenced on eighty-three nights, but on only forty-five of these did the clouds permit of fairly continuous work.

During the past year the 15-inch Equatorial has been used almost solely for spectroscopic observations. A few measures of double stars or of faint stars in the Great Nebula in *Andromeda*, or near Mr. Gore's variable star in *Orion*, were taken when the spectroscope was dismounted.

The large star spectroscope mentioned in former Reports was punctually finished by Messrs. T. Cooke and Sons in March. It works well in all respects. The single flint prism of 60° supplied with the instrument defines so well, that, with a dispersion of only 5° 7′ from A to H, it separates the pair of lines $488{\cdot}81^{mmm}$ and $488{\cdot}84^{mmm}$, and shows forty-three lines between B and C. All three lines in the ring nebula in *Lyra* can be measured without difficulty. A prism of 20° refracting angle, by Merz, promises to be very useful for faint stars, while a large compound prism by Mr. Grubb gives about as much dispersion as even the brighter stars will satisfactorily bear.

The solar spectrum was measured on twenty-one days to obtain data for reducing observations of other spectra. A very pliable formula with three coefficients devised by Dr. Becker represents the minimum deviations from A to H for the 60° prism to within about 20″, leaving outstanding errors that can be dealt with graphically.

Owing to its unfavourable position Brooks' first comet was only observed once with the large spectroscope, but both it and Fabry's comet were observed three times with a smaller instrument. Barnard's October comet was examined on eight occasions with the new spectroscope, and was photographed on the 16th, 17th, and 26th December with a 4-inch lens. The two earlier photographs show the lateral tail.

Twenty-three circulars were issued in the year, all dealing with comets, with the addition of two notes on *Jupiter's* fourth satellite. Observers are again largely indebted to Dr. H. Oppenheim for elements and ephemerides of comets.

Comet Brooks (2) of 1885 could not be found on March 9 and 11 by Dr. Becker, although the ephemeris afforded some hope that it might be visible.

The weekly time-gun and the meteorological observations have been continued as usual.

The maximum and minimum thermometers were stolen on August 2.

Mr. Edward Crossley's Observatory, Bermerside, Halifax.

The observations made in 1886 were similar to those in previous years. Of the satellite phenomena of *Saturn* thirteen observations were obtained, and ten of those of *Jupiter*. Some 180 measures with the wedge photometer were made, and forty stars observed with the Transit Circle for time. The 3-ft. Reflector has taken up a good deal of time. The dome for this instrument is now complete: it can be moved round once in five minutes or once in twenty-four hours by a water-engine with two speeds. The observing platform and gallery are suspended from the dome, and therefore the observer moves with the dome. The opening is 6 feet wide from top to bottom, and extends from the horizon to 3 feet beyond the zenith. The shutter is in two pieces, which move horizontally; and one handle opens and closes both in about one minute. The Reflector is now in good working order, and the clock drives well. The mirror will soon need re-silvering, as it has been much exposed to damp, &c., during the erection of the Observatory.

Mr. C. E. Peek's Observatory, Lyme Regis.

The equatorial (of $6\frac{4}{10}$ inches aperture) has been employed in the systematic observation of variable stars from a selected list: 146 nights were suitable for observation. Transit observations for time have been taken on all available nights. The most cloudy month was February; the clearest, December.

The Earl of Rosse's Observatory, Birr Castle.

During the year 1886 some experiments have been carried on at intervals with a view of increasing the accuracy of the apparatus for measuring Lunar Radiant Heat, but they are still only in progress.

Some photographs of the Moon were taken towards the close of the year. Several are of average good quality, and show in every case, and especially with the longer exposures, a decided advantage from the electric control of the driving clock, which had not been applied at the time when the last photographs were taken. In attempts to photograph the Great Nebula in *Orion*, however, the tilting of the speculum upon its supports

during the prolonged exposure still causes serious difficulty. No hand-correction has been as yet resorted to.

About eighty sketches of the planet *Jupiter*, which have accumulated since the last series was published, are awaiting publication when some decision as to the best mode of reproducing them shall have been arrived at.

Dr. Boeddicker has, during a considerable number of nights, been engaged upon an eye-sketch of all the Milky Way, so far as it can be satisfactorily reached in this latitude, and he hopes to represent it in more minute detail than has hitherto been done.

Meteorological observations have been carried on as usual.

Colonel Tomline's Observatory.

The work at this Observatory has suffered some interruption owing to the illness of the observer, but it is now again fully resumed. The observation of comets continues, as for some years past, to be the principal work to which the instrumental means are devoted, as it also appears to be that for which they are best fitted. Progress has been made in the reduction of previous observations, and two communications containing results of observations have been made to the *Astronomische Nachrichten* within the past year. They will be found in Nos. 2,723 and 2,754, and comprise observations of Comets 1884 III. Wolf, 1885 I. Encke's, 1885 II. Barnard, 1886 I. Fabry, 1886 II. Barnard, and 1886 V. Brooks I. At the time of the latter publication the whole of the cometary work at this Observatory had been reduced and published. Subsequently satisfactory series of observations have been made of comets Barnard-Hartwig and Finlay: the former having been observed on twenty and the latter on fifteen occasions, while both series are at the end of the year still incomplete. Efforts will be made to publish these at an early date, and thus avoid the accumulation of arrears in future.

Lieutenant-Colonel Tupman's Observatory, Harrow.

The Meridian Circle has been employed in the determination of the places of comparison stars and stars which have been occulted by the Moon. Five hundred and fifty observations of both elements have been obtained, about one-third of which are of fundamental stars. The errors of division of the circle have not been investigated; and the Nadir observation being generally difficult, owing to the vibrations of the soil, the Declinations of stars are determined by comparing them with the fundamental stars, on

the same principle as is customary for Right Ascensions. All the star observations are reduced to the mean places for the beginning of the year. Seventeen observations were made of the R.A. of the Moon's bright limb, and two of the horizontal diameter.

With the Equatoreals twenty-one occultations have been observed. The final equations in the Greenwich form have been computed for forty-seven occultations, observed between 1884, October 4, and 1887, February 10.

Comet 1886 I. (Fabry) was observed for place altogether on nineteen nights between 1885, December 7, and 1886, April 1; Comet 1886 II. (Barnard), on fourteen nights between 1885, December 27, and 1886, April 15; Comet 1886 V. (Brooks I.) on four nights between May 6 and May 20. These observations are completely reduced, and all the comparison of stars have been observed on the Meridian two or three times. Comet Barnard-Hartwig, at present visible, has been observed for place on seven nights between December 19 and January 5.

The 18-inch Reflector has been fitted with a new declination-axis, and is now sufficiently rigid; but the driving movement is very irregular.

An instrument by Kahler, of Washington, D.C., for determining absolute personal equations in observing transits, has been brought into use with the Morse chronograph.

Mr. Wigglesworth's Observatory, Scarborough.

The building of the observatory was commenced in the summer of 1884, and by the end of the year the dome was ready for the reception of the instrument. The dome is 30 feet in diameter, hemispherical in shape, and covered with very strong papier-mâché, $\frac{1}{3}$ inch in thickness, which is rivetted with copper rivets to the framework of T-iron. The shutter is of a construction originally introduced by Messrs. T. Cooke & Sons. It has the form of a semicircle striding over the dome. The tail end terminates as a pivot, while the other end, which is the base of the real shutter, rests on a rail. The shutter therefore turns round the pivot in a circle of more than 30 feet radius. It moves with great ease, and practically without noise. On the top of the dome is another rail, to steady the shutter in case of a strong wind. The slit has a width of 5 feet 10 inches at the bottom, and of fully 3 feet at the top. The dome is supported by a brick wall 13 feet in height from the floor to the top of the flat rail on which the wheels of the dome are running. The dome is turned by a cogwheel running in a rack-circle, and is moved with great ease. The rigidity of the dome is very great; it has never been noticed to shake, even when the wind was very strong.

The telescope, which was also constructed by Messrs. T. Cooke

& Sons, was set up in the dome in February 1885. The object-glass, which is a very fine one, has a clear aperture of 15·5 inches, and a focal length of 231·5 inches. The mounting is executed in Cooke's well-known style. Both the polar axis and the declination axis are of steel. There are no friction wheels to the latter, but the instrument turns with great ease in declination. The hour circle reads to 2 seconds of time, and the declination circle to 10 seconds of arc. The latter is read from the eye end of the instrument. The clamps and slow motions in right ascension and declination are worked from the eye end. The driving-clock is of the same construction as that at Dunecht, but without the electric control. There are two finders of 2·5 inches aperture. In front of the object-glass is an iris-diaphragm, by which the aperture may be reduced down to 4 inches. It is worked by a rod from the eye end, and the aperture is read off on a dial. It has been found very convenient on many occasions; the full aperture, however, gives as a rule the best definition.

The mean-time clock is believed to be a unique specimen. It was invented and made at the beginning of this century by George Prior, who was a watchmaker in Leeds, and who received a medal of the Society of Arts for the escapement in this clock. For a long time it was the standard clock of Leeds; after the death of George Prior, however, it came into the possession of Mr. Wigglesworth. The impulse received by the pendulum is independent of the train of the clock; it is given every alternate second by a spring, which is then pushed back to its starting-point by a tooth of the escapement wheel. There is a great difference between the two drops of the escapement wheel; the one is nearly three times as large as the other, and on this difference depends the impulse given by the spring to the pendulum. At the long drop the spring is pushed back; at the short drop it is released, and gives impulse to the pendulum until it is arrested by the next tooth of the escapement wheel. The length of the drop is best seen by the motion of the seconds hand, which shows alternately long and short seconds; the beat, however, is perfectly even—one second is as long as the other. The locking is effected by jewelled detent springs, which are independent of each other. Steel and zinc bars form the compensation of the pendulum, and by the addition of a very small mechanism they have also been made to act as a metallic thermometer. The clock keeps very good time, and has a clear, sharp beat.

There are two spectroscopes by Browning, a reversion spectroscope for observing the Sun, and a McClean star spectroscope.

A micrometer by Merz was kindly lent by Lord Crawford in July 1885. It has only one micrometer screw, but a fine movement can be given to the whole micrometer by two screws in

the adapter, which is a more convenient arrangement than to have two micrometer screws.

Regular observations were commenced in September 1885.

The value of the micrometer screw was determined from numerous transits of *Polaris*.

The new star in *Andromeda* was observed on fourteen nights, and the results have been published in the *Monthly Notices*.

Nova *Cygni* was examined on several occasions.

Gore's new star was examined with the spectroscope and measured from neighbouring stars on two occasions.

The dimensions of *Saturn* were also measured with the micrometer.

Comet 1885 *a* Barnard was observed for place on two nights.

Comets 1885 *d* Fabry, and 1885 *e* Barnard, were each observed on five nights.

In 1886 the observations were of a similar kind.

The dimensions of *Saturn* were measured on one occasion.

The nebula in *Andromeda* was examined on several occasions, but no changes could be detected in it. The same was the case with Nova *Cygni*.

Gore's new star was measured on three nights.

Comet 1885 *e* Barnard was observed once in this year.

Comet 1886 *f* Barnard-Hartwig was observed on twenty-one nights, and some sketches of it were also made.

Comet Finlay was observed twice.

The minor planet *Sappho* has been observed six times at the request of Mr. R. Bryant.

A want of star places has often made a delay in the reductions inevitable.

The adopted co-ordinates of the observatory have been taken from the 6-inch survey map, and are—

Longitude of Observatory $= 1^{m}\ 38^{s}\cdot9$ west of Greenwich.

Latitude ,, $= +\ 54^{\circ}\ 16'\ 30''$.

The height above the level of the sea is about 150 feet.

Royal Observatory, Cape of Good Hope.

The present report includes the period January 1 to December 31, 1886.

Observations with the transit-circle have been continued regularly throughout the year, the objects of observation being the Sun, *Mercury* and *Venus*, the stars on the list of the Cape Ten Year Catalogue for 1890, comet comparison stars, stars occulted by the Moon, stars employed in determining latitudes in connection with the Geodetic Survey, and stars employed in

zones for determining the scale-value of the heliometer. The work accomplished has been:—

Number of determinations of collimation		53
,, ,, level		510
,, ,, Nadir Point		463
,, ,, runs		455
,, ,, horizontal flexure		47
Observations of meridian mark (from April 5)		439
	Direct.	Reflex.
Number of observations of stars in R.A.	5333	634
,, ,, ,, N.P.D.	4531	634
Observations of both limbs of the Sun in both elements	191	
Observations of Mercury in both elements	109	
,, Venus ,, ,,	142	

The errors of all the new steel screws of the circle microscopes have been very thoroughly determined; and they prove, though small, to be appreciable.

Since April 5 regular observations have been made on a meridian mark, placed in the focus of a lens of about 200 feet focal length, situate to the south of the transit-circle. This mark is observed at the beginning and end of each series of observations, and it appears that the transit-circle has a very small diurnal motion in azimuth, over which observations of the mark afford an efficient control. During the winter period, April 1 to September 30, observations were regularly made on every available morning before sunrise as well as in the evening; thus a large number of double transits of circumpolars have been secured.

A great deal of time and care have been devoted to the Great Indian Theodolite, the study of its constants, and the development of the best plan of working. The errors of division of the horizontal circle have been thoroughly investigated—a work of great labour, requiring special adaptations in consequence of the peculiar form of the instrument, and of which an account will be communicated to the Society. The best arrangement of the azimuth marks has been a matter of considerable experiment. When the space between the marks and the long focus lenses is left open the images of the marks are generally ill-defined, because of ascending currents of air from the soil which has been heated by a strong sun during the day. The experiment was tried of enclosing the space between one long focus lens and the corresponding mark by means of a wooden tube or tunnel 1 foot square. The effect was to produce a great apparent improvement in the steadiness and sharpness of definition of the mark; but, unfortunately, measurements showed

that this improvement was accompanied with a slow oscillation of the mark, which seemed far more likely to produce systematic error than the rapid irregular vibrations of the marks before the tube was used. It is possible that by protecting the tube from direct rays of the Sun, by means of a long narrow shed, with sides as well as roof, this slow movement of the mark might be reduced or eliminated; but the experiment was not carried out because of its considerable cost and its problematical success. Accordingly, after much experiment, the wooden tube was removed, and the observations were resumed with open-air space between the lenses and the marks. The stability of the relative azimuth of the marks continues to be very satisfactory. The illumination of the theodolite by small incandescent lamps and storage batteries has proved most successful, and the system has been extended to the azimuth marks and the zenith telescope with the most satisfactory results. Indeed, any one who has once employed electric incandescent lamps for illumination of his instruments, especially in a windy neighbourhood, will never willingly return to the flicker, heat, and general inconvenience of oil lamps. A proposal has been made, and partly carried out, for extending electric illumination to all the instruments of the Observatory.

The following observations have been made with the Great Theodolite:—

Observations of meridian marks	73
Azimuths at greatest elongation	229
,, of N. Stars for latitude by Kapteyn's method .	32 pairs.

With the zenith telescope an investigation has been made of the value and temperature-coefficients of the screw by observations in summer and winter, and 104 pairs of stars have been observed for difference of meridian zenith distance.

The general rule has been adhered to of observing all comets visible south of the Equator, or which otherwise cannot be conveniently observed in the Northern Hemisphere. The fulfilment of this programme has led to a considerable amount of work in the past year.

Winnecke's Comet, which was only seen during fourteen days in 1875, and not at all at the opposition of 1881, was swept for and found by Mr. Finlay on August 19, $5\frac{1}{2}^{\circ}$ from the predicted place of Dr. Lamp's *Ephemeris* (*Astron. Nach.* 2,720, 2,731), corresponding to a time of perihelion passage twelve days earlier than predicted.

On Sunday, September 26, Mr. Finlay discovered another periodic comet, which, if identical with the comet of De Vico, has not been observed since the year of its discovery in 1844.

The following is a list of the observations of comets made during the year:—

	Fabry was observed on	31	nights	between	May 1	and	July 30.
Barnard	„	18	„	„	May 29	„	July 26.
Brooks I.	„	13	„	„	July 5	„	July 30.
Winnecke	„	32	„	„	Aug. 19	„	Nov. 29.
Finlay	„	34	„	„	Sept. 26	„	Dec. 28.

A paper containing the results of these observations will be communicated to the Society at the March meeting.

Occultations of thirty-two stars and three planets by the Moon have been observed during the year.

The result of observations of stars with the transit-circle for 1882, 83, 84, and till 1885, February 7, are reduced, and will be passed through press by H.M. Astronomer when in England. The Catalogue for 1885, from the meridian observations 1879–85, is in progress.

Aided by the vote of 300*l.* from the Government Grant Fund of the Royal Society, the services of Mr. C. Ray Woods have been continued as photographic assistant.

The extension of the Photographic *Durchmusterung* has been pushed forward as rapidly as possible. Pictures for the whole sky from declination $-57°$ to $-90°$ have now been obtained in duplicate, and considerable progress has been made in further zones towards the Equator. The following amount of work has been secured during the year:—

Perfectly successful *Durchmusterung* plates, exposed one hour in clear sky	263
Plates for special purposes	37
Plates exposed for more than an hour, such as comets, star clusters, &c.	11
Failures	16
	327*

The new photographic objective of 9 inches aperture and 9 feet focus, presented by Mr. Nasmyth, has been received from Mr. Grubb, and also a new 6-inch Dallmeyer rapid rectilinear lens (bought by a grant from the Government Grant Fund of the Royal Society). These, together with a guiding telescope of 5 inches aperture and $9\frac{1}{2}$ feet focal length, have been mounted after a design by H.M. Astronomer on a single powerful stand at his private expense, and the work has been continued since September 30 with the new apparatus. This apparatus is fitted with refined means for centring, and with fine scales for focussing, and also with means for giving definite orientation,

* The dismounting of the old apparatus, and the erection of the Nasmyth telescope, &c., in a more convenient observatory, caused some interruption of regular work.

defined by a ground edge on the sensitive plate, which edge rests by spring pressure upon two cylinders that have rigid relation to the declination axis. The dark slides are of metal. The whole apparatus was made by Mr. Grubb, and is found to give very satisfactory results.

Each picture of the *Durchmusterung* photographs taken with the Dallmeyer lens has now a corresponding picture for the central position of its area (perfect over four square degrees), taken simultaneously by means of the Nasmyth lens, and showing stars to a higher order of magnitude. The enumeration of the stars in the corresponding areas of the two pictures will furnish very valuable data for discussing the distribution of stars of different orders of magnitude, after the comparative light-factor for the two lenses has been accurately determined. Some pictures of remarkable star clusters, &c., have been obtained with the Nasmyth lens.

For the reduction of the *Durchmusterung* pictures, H.M. Astronomer has received a noble offer of co-operation from Prof. J. C. Kapteyn, of Grœningen. Appreciating the importance of the work, and the suitability of the means to the end, Prof. Kapteyn proposed to devote his own time and that of three assistants during the next seven years to measurement and reduction of the *Durchmusterung* photographs, and the preparation of a catalogue somewhat resembling that of Argelander. Such an offer from one so capable and so devoted could not but be gratefully and cordially accepted. Accordingly the pictures from S.P.D. 0° to 13° were forwarded to him, together with duplicate plates of an area in the neighbourhood of the Equator for comparison with Argelander. This comparison showed that whilst with a *very few* exceptions (probably red stars) *all* the stars of the *Durchmusterung*, including those of the 9·5 magnitude, are shown on the plate, there are about 30 per cent. more stars on the plates than are contained in Argelander's work. After much discussion by correspondence, a method of observation was arranged by which the Right Ascensions and Declinations of the stars, reduced to the equinox of the Catalogue, are obtained directly from the instrumental measurement; the instrumental results require only small final corrections for index errors, orientation, &c., which can be easily tabulated from comparison of the instrumental and tabular R.A. and Declin. of the known stars. A rough temporary apparatus was arranged by Prof. Kapteyn, which it was resolved to employ for obtaining preliminary plates of the stars within 10° of the South Pole, and with the working catalogue so formed, it will be then easy to observe all these stars in zones with the Cape transit-circle. Thus the first portion of the *Durchmusterung* would be published with places exact to 1″ of arc. With the preliminary apparatus Prof. Kapteyn had already measured in duplicate all the stars within 10° of the South Pole from R.A. 23^h 10^m to 9^h 50^m. The accuracy obtained with the

rough apparatus has exceeded expectations, as will be shown by the following comparison of the instrumental R.A. and Declin. with corresponding tabular places of the Cape 1880 Catalogue:—

By	Deduced Decln. of zero of scale.	Index error in R.A.
	° ′	″
Zone IX. Stone 2948	80 29·5	+ 16
3290	29·5	+ 15
3380	29·5	+ 10
3457	29·6	+ 18
3680	29·5	+ 18
4084	29·7	+ 18
4486	29·5	+ 20

The Declinations are read off by estimation to 0″·1, from a glass scale, graduated to 1′ of arc, placed in focus of the small telescope by which the photograph is viewed; and the R.A. is read off by estimation to 2^s of time, by a small circle graduated to 20^s attached to and rotating with the axis, which serves as the polar axis of the arrangement. There seems to be little doubt that, with a more refined measuring apparatus the places of stars can be determined from the photographs to a single second of arc, without much additional trouble on the part of the observer. An apparatus amply providing for this accuracy has been devised by H.M. Astronomer, and he hopes to be able to have it executed during his approaching visit to Europe.

A very laborious attempt has been made since July 20, 1885, to photograph the Corona by Dr. Huggins's method. From time to time some of the pictures obtained showed persistent similarity, under conditions which appeared to preclude the possibility of instrumental error, but no gradual change could be traced in these appearances, such as one might expect in the representation of successive features of the true Corona.

With every confidence in the method, and with laborious care, some hundreds of these pictures have been taken and examined in different ways and in different lights, and the appearances have also been discussed in relation to the elongations of *Mercury* and *Venus*, as suggested by Dr. Huggins. The most hopeful series have been independently drawn by Mr. Wesley, with results as to the general features of the pictures of the same day coinciding with those remarked at the Cape, but the results, while sometimes leading to hope of success, have never brought the conviction that the true Corona had been really photographed. The crucial test as to whether the dark body of the Moon could be photographed against the background of the Corona was tried under favourable atmospheric

conditions on the occasion of the partial eclipse of August 29. No trace whatever of the dark body of the Moon outside the Sun's limb could be discovered on the pictures, and it appears that further experiments in this direction, to be successful, must be made at a higher altitude, or at a time when the Sun's Corona is brighter than the recent eclipse observations show it to be at present.

The new observatory for the heliometer is completed. Messrs. Repsold report that the new heliometer will be finished in the end of February, and H.M. Astronomer has received instructions from the Admiralty to visit Europe for the purpose of inspecting it before it is sent to the Cape.

The Geodetic Survey continues to make considerable progress, notwithstanding somewhat disheartening conditions—viz. reduction of the vote by one-third of its amount, on account of the depressed financial condition of the Colony. In consequence of this reduction the services of Lieut. Laffan, R.E., have been transferred to the Survey of British Bechuanaland, the staff otherwise reduced, and the equipment and transport reorganised. Captain Morris, R.E., has carried on the field work in these new and more trying conditions with the same energy and ability as formerly. The triangulation has been carried from Natal through Griqualand East to King William's Town in the Cape Colony, and the stations have been selected and beaconed from King William's Town to Port Elizabeth.

H.M. Astronomer has taken part in measurement of a base line at Port Elizabeth, of which an account will be communicated to the Society. The extension of this base to the first great side is now in progress. The subsequent measure of the angles of the triangles already selected and beaconed between Port Elizabeth and King William's Town will be completed in June, when Baily's existing triangles between Sir T. Maclear's southern stations and Port Elizabeth will complete a chain of triangles about 1,300 miles in length, checked by three base lines and with numerous astronomical stations, which should afford some valuable geodetic data.

Lieut. Laffan, R.E., has compared his personal equation with Mr. Pett at the Observatory on four nights, not by the usual methods, but by actual determination of the longitude of a hut on the Observatory grounds by telegraphic exchange of signals, as in the ordinary process of a longitude operation; the results, therefore, include the relative personal equation of the observers in giving and receiving signals as well as in determination of time.

The longitude of the following points on the Geodetic Survey have been determined by telegraphic exchange of signals with Captain Morris:—

Umtata, by exchange on 6 nights.
Berlin, „ „ 4 „

and the longitude of Dryhartz, in British Bechuanaland, by exchange of signals with Lieut. Laffan, R.E., on five nights.

The heavy pressure of a great variety of work requiring the close personal attention of H.M. Astronomer has rendered it impossible to complete the reduction of the observations of *Victoria* and *Sappho* in 1882, but it is expected that the work will be pushed to completion before the end of the year.

The Meteorological Observations made in the year 1885 at the Observatory, together with those taken in different parts of the Colony, have been printed in the Reports of the Cape Meteorological Commission.

Hong Kong Observatory.

The second annual volume was published early in the summer, and the third volume will probably be ready for distribution within a few months. The meteorological observations and researches have been extended, and kept up to date since the appointment of an additional clerk. Absolute magnetic observations were made monthly, and Sir W. Thomson's automatic tide-gauge was erected and worked since the end of October.

The electric time-ball was dropped as usual at 1 P.M., and the sidereal standard clock was kept going without being touched throughout the year. As soon as two years' ten-day rates are available, it is intended to re-examine the coefficients.

Micrometric measures of *Jupiter* and *Saturn* occasionally made since 1879 have been reduced, and will be published in the astronomical Report.

Notes on some Points connected with the Progress of Astronomy during the past Year.

Discovery of Minor Planets.

The following eleven minor planets were discovered in the year 1886:—

No.	Name of Planet.	Date of Discovery, 1886.	Discoverer.	Place of Discovery.
254	Augusta	Mar. 31	Palisa	Vienna
255	Oppavia	31	,,	,,
256	Walpurga	Apr. 3	,,	,,
257	Silesia	5	,,	,,
258	Tyche	May 7	Luther	Dusseldorf
259	Aletheia	June 28	Peters	Clinton
260	Huberta	Oct. 3	Palisa	Vienna
261	Prymno	31	Peters	Clinton
262		Nov. 3	Palisa	Vienna
263		3	,,	,,
264	Libussa	Dec. 22	Peters	Clinton

Minor planet No. 253, discovered by Herr Palisa on November 12, 1885, has been named *Mathilde*.

The Comets of 1886.

Including the periodic comet of Winnecke, six comets have been discovered during the year. It will be more convenient to describe these in the order of their discovery, than according to their several dates of perihelion passage or catalogue order.

The first (known as 1886, Comet V.) was discovered by Mr. Brooks, of Phelps, New York, on April 27, in the constellation *Cassiopeia*, and moving south and east. At the time of discovery it was round, tolerably bright, and about one minute in diameter. The comet was approaching both the Sun and the

Earth, and the brilliancy consequently increasing. The maximum brilliancy was attained about June 9, near the date of perihelion passage, when it had twenty times the intensity that it possessed when first seen, but was too near the Sun to permit of observation. After perihelion, the comet was not well situated for observation, and does not seem to have been seen. The observations are well represented by a parabola.

Four days later, on May 1, Mr. Brooks discovered another comet in the constellation *Pegasus* (designated 1886, Comet III.). This comet was fairly bright, and had on May 3 a short tail, eight minutes in length. Owing to the morning twilight the comet soon became a difficult object to observe, and was apparently lost sight of in the third week of May, but the change of form in the comet was interesting. On May 20, Col. Tupman could see no trace of a head, and the two ends of the tail were so similar, it was impossible to say by mere inspection, which was the head. On May 22 Dr. Tempel gave a very similar description, but suspected two very slight condensations in a spindle-shaped nebulous mass, about twelve minutes long.

As in the previous case the orbit is apparently parabolic, but some interest attaches to the elements, since at the ascending node which the comet passed on July 9, its distance from the Earth was only 0·075, and therefore might have originated a meteor-radiant, visible in the southern hemisphere, the co-ordinates being approximately $\alpha = 19°$ and $\delta = -42°$.

On May 22, Mr. Brooks discovered a third comet (1886, IV.), which does not appear to have been observed very frequently, the more to be regretted, as the comet's orbit will probably prove to be elliptic. Dr. Oppenheim, failing to represent the path with sufficient accuracy by means of a parabola, has computed an elliptic orbit of nine years' period, which fairly well represents the few observations at his command.

Comet 1886 VI. is the periodic comet of Winnecke, detected by Mr. Finlay at the Royal Observatory, Cape of Good Hope, on Aug. 19, the possibility of the comet being found in the northern hemisphere during the summer months not having been realised. The last return of this comet was in 1880, when, owing to its proximity to the Sun, it passed unobserved. In the interval, 1880–1886, the comet underwent very considerable perturbations from *Jupiter*, to which planet, in heliocentric longitude 110°, it can approach within 0·06. No accurate calculations of the perturbations were undertaken, but Dr. Palisa gave sweeping Ephemerides from elements approximately corrected. These elements show that the chief effect of the perturbation has been still further to diminish the mean motion, which had been steadily decreasing since the re-discovery in 1858. The passage through the perihelion was, however, twelve days earlier than was predicted by Dr. Palisa. It cannot be doubted but that rigorous calculations will be made in order to connect the observations of this year with those of the earlier apparitions,

since, according to the late Dr. Oppolzer, the theory of the comet cannot be satisfactorily reconciled with observation on the purely gravitational theory, but that the mean motion and eccentricity require the correction of small terms, depending on a supposed resisting medium.

On September 26, Mr. Finlay discovered another comet, in the constellation *Scorpio*, having small south-easterly motion. The comet was round, one minute in diameter, and without tail. As soon as the elements were computed, it was seen that they strongly resembled those of De Vico's comet of short period, which had not been seen since 1844. There are, however, some difficulties in accepting the suggestion that the two comets are identical, and the doubt cannot be cleared up till the mean motion of the comet is sufficiently well determined to permit the rigorous calculation of the perturbations of the comet by *Jupiter* (and possibly *Mars*) in the interval.

The period assigned by Dr. Brunnow was 5·466 years, and if we assume that either eight or seven returns of the comet had occurred between 1844 and the present time, we must admit either the action of very considerable perturbation, which is not likely, or that Brunnow's period was more in error than seemed possible, though it is admitted that the change of form in the comet during visibility in 1844 may explain the existence of a larger error than has hitherto been suspected. The more accurate elements that have been computed from a more extended series of observations, and in which no assumption of the axis major has been made, agree in giving a period considerably longer than that found by Dr. Brunnow, so that it is not impossible that the two comets may not be identical, but two moving in a similar orbit, an example of which was seen in the case of Comets 1843 I., 1880 I., and 1882 II.

The sixth comet of the year was discovered on October 4 by Mr. Barnard, and independently by Dr. Hartwig on the following day. The comet at discovery was round and tolerably bright, and was increasing in brilliancy. By October 29 a short broad tail was visible, and early in December this tail had increased to several degrees in length, and a shorter tail of 15′ in length, and distant 40° of position angle had been developed. These details have been satisfactorily photographed by Von Gothard, of the Physical Observatory of Herény. It was seen with the naked eye in Turin on November 21, but was too near the morning twilight to become a conspicuous object. The orbit is apparently parabolic.

In addition to these comets, it is well to remark that Olbers' Comet, to which reference was made in the last Annual Report, has not yet been detected, and that as the most probable time of perihelion passage has now been reached the search should be severely maintained. A comet, which was discovered by Tempel on November 27, 1869, and re-discovered by Swift on October 11, 1880, has probably passed this year through perihelion unde-

tected. The orbit has been rigorously computed by M. Bossert of the Paris Observatory, who gave an ephemeris to assist the search. It is a peculiarity of the comet that it is well situated for observation at alternate returns, and this approach was unfortunate, the theoretical brilliancy never attaining one-tenth of that possessed by the comet at the last recorded observation.

W. E. P.

The Total Solar Eclipse of 1886, *August* 28–29.

The expedition sent out to Grenada, West Indies, to observe this eclipse, consisted of the following persons: Captain Darwin, Mr. Lockyer, Mr. Maunder, Father Perry, Dr. Schuster, Professor Thorpe, and Mr. Turner. Professor Tacchini also accompanied the expedition on behalf of the Italian Government. The observers divided into several parties on reaching Grenada, as a precaution against purely local masses of cloud, or bad weather; it being also arranged that observations should be made as far as possible in duplicate. Although the weather at the time of the eclipse was not all that could be desired, successful observations were secured at three stations; at the fourth the Sun was obscured by heavy clouds.

The following is a brief account of the results obtained, taking the stations in order from the south:—

Station I.—*Prickly Point*, lat. 12° 0′ N., long. 61° 46′ W. Captain Darwin with the coronograph exposed six plates during totality, one for five seconds, one for ten seconds, and four instantaneous. During the partial phases he obtained more than twenty satisfactory photographs, and on the day before the eclipse, fifteen. These were all taken with the object of testing Dr. Huggins's method for photographing the Corona without an eclipse, and the result, as far as is yet known, is unfavourable to that method, under such conditions of hazy sky and low sun as were obtained.

Captain Darwin also took one photograph with the prismatic camera.

Dr. Schuster obtained four photographs of the Corona with a 5-foot camera, and two of the coronal spectrum, with slits radial and tangential respectively.

Station II.—*Hog Island*, lat. 12° 0′ N., long. 61° 44′ W. Professor Thorpe, assisted by Mr. Lawrance, obtained a satisfactory series of photometric measures of the intensity of the Corona. He made in all fifteen separate and independent comparisons of the coronal and diffused light beyond the visible edge with a Swan electric lamp of known photometric value, by a method arranged by Captain Abney. During the latter part of totality

the coronal light was dimmed by haze, but he sees no reason for thinking the measures made in the first hundred seconds other than perfectly trustworthy. Relying on these seven only, the final photometric values obtained are not very different from those found by Professor Harkness in the 1878 eclipse.

Station III.—*Boulogne, near Grenville*, lat. 12° 9′ N., long. 61° 38′ W. Professor Tacchini made a careful comparison of the prominences detected by the spectroscope before and after totality with those seen during totality, and found important differences between them, viz.: all prominences showed themselves larger and taller during an eclipse, the upper portions being white when the prominence exceeds 1′ of arc in height, while some very fine prominences seen during totality were not discernible in full sunshine at all; these latter were almost entirely white, and their luminous intensity was small, so that they were not visible to the naked eye unless they extended beyond the brightest part of the Corona. He also observed the spectrum of the "flash" noticed by Professor Young in 1870, and traced it to a much greater height than before.

Mr. Turner obtained a qualified confirmation of Mr. Lockyer's Egyptian observations with regard to the order of appearance of the bright lines near F in the spectrum of the inner Corona. During totality he looked for currents in the Corona, but obtained no satisfactory results.

Station IV.—*Green Island*, lat. 12° 14′ N., long. 61° 35′ W. Cloudy during totality. Mr. Lockyer considers, however, that important information was obtained by preliminary drills as to the number of photographs which could be taken during totality by careful management.

Station V.—*Hermitage, Carriacou*, lat. 12° 27′ N., long. 61° 29′ W. Father Perry made observations of the order of appearance of lines in the coronal spectrum near E., and observed 1474 K and other short bright lines two minutes before totality. During totality he looked for the carbon flutings seen by Professor Tacchini, but with a negative result.

Mr. Maunder obtained seven photographs of the Corona with a 5-foot camera, exposures varying from $0^s{\cdot}2$ to 40^s, and two photographs of the coronal spectrum with slits radial and tangential.

Almost at the last moment another observer arrived on the scene. Mr. W. H. Pickering, from Boston, Mass., took up his position in Fort George, lat. 12° 3′ N., long. 61° 45′ W., armed with a photoheliograph of 38 feet focal length. He exposed a number of plates during totality, and also organised a series of observations of the shadow bands.

The observers owe a very large debt of gratitude to the Governor of Grenada, who helped them in every way, and they received invaluable assistance from the leading officials, and from the officers and crews of H.M.S. *Fantôme*, H.M.S. *Bullfrog*, and

H.M.S. *Sparrowhawk*, both in transport and preparations for observing, and in the actual observations. A number of discs had been taken out with the view of repeating Professor Newcomb's observation of 1878 on the coronal extension, and fairly accordant results were obtained by the following observers at the different stations:—

I. Captain Maling, Colonial Secretary.
II. Captain Archer, of H.M.S. *Fantôme*.
III. Lieut. Smith, of H.M.S. *Sparrowhawk*.
IV. Captain Hughes, Protector of Immigrants, and Mr. Belton.
V. Captain Masterman and Mr. Osburn, of H.M.S. *Bullfrog*.

At Station II. also Lieuts. Douglas and Bairnsfather, of H.M.S. *Fantôme*, made a series of photometric measures with an integrating apparatus, which agree with Professor Thorpe's general results. The Governor of Grenada, the Chief of Police, the Clerk of the Council, Dr. Boyd, Mr. Elliott (Government Botanist), and Captain Oldham, of H.M.S. *Sparrowhawk*, were all busily engaged at Station IV., and were prepared to assist in the photographic operations.

On the whole, the expedition may be considered a very successful one, and the passing clouds which obscured part of the phenomenon at the more fortunate stations served perhaps to remind the observers how nearly they had escaped complete failure. H. H. T.

Professor Hall's Researches on the Orbits of the Six Inner Satellites of Saturn.

In Appendix I. of the Washington Observations for 1883 Prof. Asaph Hall communicates the positions of the six inner satellites of *Saturn*, observed with the 26-inch refractor, and the results of the computations to which they have been subjected.

The observations of Titan, which extend over nearly ten years, from August 1874 to February 1884, consist partly of measurements of differences of Right Ascension and Declination between the satellite and the centre of the planet, and partly of measurements of position-angle and distance. The observed positions are compared with the corresponding places computed with the values of Bessel's tables in vol. 9 of the *Astron. Nachrichten*. Bessel's determination of the elements of the orbit there given is founded upon the first series of his own heliometrical measurements of Titan, taken in 1830, the mean motion of the satellite in its orbit and the motion of the line of apses being deduced from a careful discussion of the scanty observations of conjunctions of the satellite with the centre of the planet made by Halley, Cassini, Herschel, and Köhler. The

Washington computations show that only small corrections of the tabular values are demanded by the Washington observations. Indeed, the correction of the motion of the apses is left doubtful; for, while the earlier series of observations made from 1874 to 1882 indicate a slight augmentation, only the last series made 1883–84 show a diminution, and it will have to be decided by further evidence what is the true motion.

From his computations of the micrometrical measurements of Rhea, Dione, and Tethys, which were made in the years 1874 and 1875, Prof. Hall draws the conclusion that the eccentricities of the orbits are left practically undetermined, and also that the planes of the orbits probably coincide very nearly with the plane of the ring. For the determination of the mean motions of the satellites he assumes that the mean longitudes for the epoch 1858, which Jacob has deduced from his Madras observations, are free from error, and the values of the daily motion resulting from the positions of 1858 and 1875 are then partly corrected with the help of the conjunctions observed at Washington in the years 1882 to 1886. In the case of Mimas, the mean motion is simply deduced from seven conjunctions, observed within three years and a quarter. But, as the adopted motion leaves an error of about half an hour in Herschel's trustworthy observation of October 18, 1789, the value cannot be accepted as sufficiently correct. A. M.

The Argentine General Catalogue of Stars.

It was only in the middle of the year 1872 that observations with the Cordoba Meridian Circle were commenced, and by the end of 1880 no less than 145,000 observations had been made, suitable for the General Catalogue, and more than 105,000 zone observations. It is probable that the whole of the meridian work of all the other observatories in the world put together during the same interval would fall short of these numbers. Only seven years ago the state of our knowledge of the southern heavens was deplorable. The publication, in 1881, of Mr. Stone's great work at the Cape and of the present truly wonderful work of Dr. Gould and his able assistants, during the last few months, has suddenly turned the scale so completely that the southern heavens are now more thoroughly surveyed than the northern, and must remain so until all the zones of the Astronomische Gesellschaft have been united into a complete catalogue. The rapidity with which the reductions have been effected and published is no less amazing than the observations themselves. Nothing like it has been known in the history of astronomy.

The instrument is described in the introduction to the observations in 1872. Several volumes of the observations and the Zone Catalogue have already been published. The present

volume forms No. XIV. of the series. It contains the places of 32,448 stars south of the parallel of N.P.D. 113° in the body of the Catalogue, and of 1126 stars in remarkable clusters arranged as separate small catalogues. The epoch is 1875·0. The arrangement of the Catalogue exhibits separately each year's results for each star. The annual precessions and secular variations, the epoch of observation, the number of observations and references to other catalogues are given. Most of the stars have been observed at least three times. The adopted mean places of the time and circumpolar stars, used for the determination of the instrumental corrections in each year, are given in the corresponding volumes of observations.

The Right Ascensions of the Catalogue depend exclusively upon 75 time stars of the American *Nautical Almanac*. The declinations are independent.

The stereotype plates of the Catalogue have been presented to the Royal Astronomical Society by Dr. Gould, with the consent of the Government of the Argentine Republic.

The Harvard Catalogue of 1213 *Stars for* 1875·0.

This work, which represents a large part of the labours of Prof. W. A. Rogers for the last fifteen or sixteen years, forms Part I. of vol. xv. of "Annals of Harvard College Observatory." The observations on which it depends were made with the large Meridian Circle, described in vol. viii., between 1870 November and 1879 January. The stars are of two classes; 492 being fundamental stars from Dr. Auwers' Catalogue in "Publication der Astronomischen Gesellschaft," XIV., the remainder, termed secondary stars, being miscellaneous stars observed for various purposes. The observations were concurrent with those of the zone +50° to + 55°, A.G.

The observations of the fundamental stars have been printed in vol. xvi. with an elaborate and masterly Introduction by Prof. Rogers, giving the method of reduction in great detail. The Introduction to the present Catalogue contains the mean places of these fundamental stars separately for each year, and the star ledgers of such of the other stars as are not given in vol. x. or xii.

Instead of the usual spider-lines, a reticule ruled upon glass was employed. The Declinations were measured by recording on the chronograph transits over very oblique lines. For a number of years only two microscopes were used for reading the circle; but Prof. Rogers has elaborately investigated the reduction of the mean of two to the mean of four from the observations of subsequent years.

The Right Ascensions of Publication XIV. were used in determining clock error; hence, for the fundamental stars the

Right Ascensions of the Catalogue are almost exactly reproductions of Auwers'. The same applies to the Declinations. The errors of the circle and accumulated errors of the microscopes were determined by and expressed in terms of Auwers' system of Declinations. The discussion of the observations of the fundamental stars (which are very numerous and of a high degree of accuracy) demonstrates the homogeneity of Auwers' systems. The places of the remaining 720 stars have a corresponding degree of accuracy. For Bradley's stars, Dr. Auwers' original proper motions are given in the Catalogue, and were used for reduction to mean epoch.

The Pulkowa Catalogue of 3542 *Stars for* 1855·0.

This Catalogue, which forms a portion of vol. viii. of the "Pulkowa Observations," has been formed from the observations published in vols. vi. and vii. It contains all Bradley's stars from the Pole to 105° N.P.D., except the Pulkowa fundamental stars, all other stars down to the 6th magnitude inclusive in Argelander's *Uranometria Nova* in the same portion of the heavens, and some other stars which have been added to the observing list from time to time for special purposes. The observations were made with the Repsold Meridian Circle, described in the introductory volume, between the years 1840 and 1869, by MM. Sabler, Döllen, Lindhagen, Winnecke, and Gromadski. The reductions were conducted throughout by M. von Asten.

Each star was observed four times; once in each of the four positions of the instrument obtained by reversing the axis and interchanging the object-glass and eyepiece. The Right Ascensions depend upon those of the Pulkowa Fundamental Catalogue, the Sun not having been observed with this instrument. The Declinations are independent, having been determined from observations of the horizontal collimators combined with the known colatitude. The large number of stars and the completeness with which the plan of observation was carried out make this one of the most valuable catalogues in existence. The delay in the publication has enabled Dr. Auwers' new proper motions to be inserted in the work, and to be used in the reduction to mean epoch.

Professor Schönfeld's Extension of the "Durchmusterung."

An important work has been issued within the last few months from the Royal Observatory of Bonn. Argelander's *Durchmusterung*, or survey of the northern heavens from the Pole to 2° of South Declination, has been carried down by

his successor, Professor Schönfeld (who in conjunction with Professor Krueger was associated with the late Professor Argelander in the former part of the work), to 23° South Declination, and the results are now in the hands of astronomers.

Professor Schönfeld commenced observing on January 6, 1876, and at first proposed to carry his survey down to 24° or 25° South Declination, so as to overlap by a degree or so the northern limit of the Cordoba zones. It was found, however, that −23° was the extreme limit for satisfactory observation. In view of the lower altitude of the stars to be observed, it was decided to substitute for the small comet-seeker of 34 lines aperture, employed in the earlier work, a telescope by Schröder of 6 inches aperture and 6 feet focal length—a change which was further recommended by the fact that for several years Professor Schönfeld had been engaged in magnitude comparisons with a telescope of the same aperture at the Mannheim Observatory. With this instrument, fitted with an eyepiece of 26 mag. power, having a field of 1° 44′, the survey was worked in zones; and the stars thus observed number 133,659 between −2° and −23°, with an additional 1173 stars falling beyond these limits. At the same time, with a view to the more satisfactory designation of the fainter stars, the magnitude limit was extended to 10·0. The resulting catalogue is arranged in zones of 1° of Declination on the same plan, and calculated for the same epoch (1855·0) as the sections of the earlier work, and forms Vol. VIII. of the "Astronomische Beobachtungen auf der Sternwarte zu Bonn."

The catalogue is accompanied by an Atlas, in which the charts are arranged in sheets of one hour of Right Ascension each, with an overlap of four minutes on either side, and extend in Declination from −1° to −23°. The Atlas will be completed in four parts, of which two only have as yet appeared. These contain Hours 0 to xi. (with the exception of Hour vii.), and Hour xxiii.

This valuable work, completing the survey of the heavens on a uniform plan within the limits effectively practicable at an Observatory in central Europe, is appropriately inscribed by Professor Schönfeld to Argelander's memory.

The Second Armagh Catalogue of Stars.

This Catalogue embodies the whole of the meridian work done at the Armagh Observatory since the publication of the first Armagh Catalogue. It contains the places of 3300 of Lalande's stars, from observations between 1859 and 1883 inclusive, reduced to the epoch 1875·0.

The Right Ascensions depend on the standard stars of the *Nautical Almanacs* of the period, four or five of which were

observed on each night. These stars were not observed in Polar Distance. The Declinations of the Catalogue depend upon the Nadir observation which was made every night, the assumed colatitude, and the division errors determined by Dr. Robinson many years ago. The refractions employed were Dr. Robinson's. The precessions are given to three places and two places of decimals in R.A. and N.P.D. respectively, but not the secular variations. The references to other catalogues are copious, and are apparently complete. The observations upon which Dr Robinson's Catalogue of 1000 Lalande's stars depend are included in the present volume.

It was only in February 1882 that Dr. Dreyer was appointed to the directorship of the Observatory, at which time most of the work was unreduced.

Dr. Kam's Catalogue of 5455 *Small Stars.*

Scattered through the volumes of the *Astronomische Nachrichten* are a great number of determinations of the places of small stars, generally comparison stars, not to be found elsewhere. Prof. Schjellerup formed a most useful index to all these stars in the first sixty-six volumes, by reducing all their places approximately to 1855·0, and giving a reference to the volume and page where the accurate place could be found ("Publication der Astron. Gesell." VIII.). That work still remains useful for all stars determined by equatorial comparison with others. Dr. M. Hoek, late Director of the Utrecht Observatory, commenced the task of forming a proper catalogue of all such stars as had been observed with meridian instruments, and his successor, Dr. Kam, has completed it. The body of the work is a catalogue of 4890 meridian observations of 4350 stars, reduced to the epoch 1855·0 by the application of precession. The precessions, secular variations, and third terms are given for the same epoch, a reference to the volume and page of the *Ast. Nach.*, and the name of the observer and observatory. This is accompanied by copious notes and a comparison of every star with its place in the Bonn *Durchmusterung*—the whole involving an immense amount of labour which will be duly appreciated by all who are engaged in equatorial comparison work, and will ultimately assist in determining the proper motion of these small stars.

The Great Comet, 1882. *II.*

Dr. Gill has recently published a complete account of the observations of this comet, which were made at the Royal Observatory, Cape of Good Hope.

Utilising all the means at his disposal, Dr. Gill succeeded in securing a fairly continuous series of positions of the comet from 1882, September 7, to 1883, May 12, to accomplish which, observations were made with the Indian Theodolite, the Transit Circle, the Heliometer, and the 6-inch and 7-inch Equatorials.

In Table I. is given the daylight observations made with the Indian theodolite on September 16, 17, and 18, before and after the comet passed on to the Sun's disc; and the resulting R.A. and declination are computed for the times of observation.

Table II. gives the meridian observations with the Transit Circle. These consist of three observations by Dr. Gill in September 17, 18, and 22, and a series between January 9 and 30, made by Mr. Maclear, who endeavoured to observe the brightest part of the nucleus.

Table III. gives the apparent places of the comet in R.A. and N.P.D. from a long series of observations, with comparison stars made with the Equatorials from 1882, September 7, to 1883, May 12. In the majority of these observations, the centre of the nucleus, or patch of light, was supposed to be observed, but towards the end of the series it was found that one of the observers always observed a more condensed part which slightly followed this centre.

The results of Dr. Elkin's observations with the Heliometer are given in Table IV. In these observations, as in those made with the Equatorials, the same portion of the nucleus was not always observed. The complex character of the nucleus of this comet, and the uncertainty that must exist as to which portion of it the observations refer, will present serious difficulties to the computer.

The memoir is illustrated by several interesting sketches of the head and nucleus of the comet, and by copies of the unique series of photographs so happily secured by Dr. Gill.

Professor Hall's Determinations of Stellar Parallax.

Professor Asaph Hall has published in an Appendix to the Washington Observations for 1883, a further series of observations for stellar parallax.

The method adopted was the same as that employed for the earlier observations, viz. to observe the differences of Declination of the principal stars with respect to small stars near them which are supposed to have no physical connection with the large stars. The method of measuring differences of Declination was chosen because the measurement of distances with the filar micrometer of the Naval Observatory has been found more accurate than that of angles of position; and also because observations had shown that there was no sensible term depending on the temperature in the value of a revolution of the micrometer screw.

Professor Hall's results for the four stars observed give the following values of the parallax :—

40 (o^2) Eridani	$\pi = +0''.223 \pm 0''.0202$
6 B Cygni	$\pi = -0''.021 \pm 0''.0077$
α Lyræ	$\pi = +0''.134 \pm 0''.0055$
61 Cygni	$\pi = +0''.270 \pm 0''.0101$

The parallax of 40 (o^2) *Eridani* was obtained by measures of the difference of Right Ascension of a star of the eleventh magnitude 32^s following and 48″ south of the principal star. The distance was so great that, with the power of 383 employed, it was necessary to move the eyepiece in order to bring the stars successively into the field, which introduced an element of considerable difficulty. Dr. Gill's value of the parallax of this star is $0''.166 \pm 0''.018$.

The negative value of the parallax obtained for 6 B *Cygni* is suggested by Professor Hall as indicating a parallax of the star of comparison or some systematic error in the observations of the summer and winter months. The result is strikingly different from Sir R. S. Ball's provisional determination—

$$\pi = 0''.482 \pm 0''.054$$

An error having been detected in the reduction of the observations for determining the parallax of α *Lyræ* and 61 *Cygni*, made in 1880 and 1881 (noticed in the Report for 1882), the result now given for α *Lyræ* is from a re-reduction of the original observations. In the case of 61 *Cygni* two additional series of observations, near the times of the maximum positive and negative coefficients of parallax, were made in 1885 and 1886 and combined with the earlier series re-reduced. Professor Hall's concluded value of the parallax is much smaller than what has been determined by other observers. The author calls attention to the discrepancy, but considers that the results appear to be the best that can be derived from the observations.

Stellar Photography.

The most notable records in relation to stellar photography during the past year are embodied in—

I.—A remarkable article entitled "An investigation in Stellar Photography," forming part of vol. xi. of the *Memoirs of the American Academy*, by Professor Pickering.

II.—A Monograph on Astronomical Photography, by Admiral Mouchez, in the *Annuaire du Bureau des Longitudes*, Paris, 1887.

III.—The article on Stellar Photography contained in the February number of the *Nineteenth Century*, by Mr. Common.

IV.—The Successful Application of Photography to the Determination of Stellar Parallax, by Professor Pritchard, in the January number of the *Monthly Notices* of the Royal Astronomical Society.

V.—A paper in the *Astronomische Nachrichten*, No. 2737, on the photographic work executed in the Imperial Observatory of Potsdam.

Of some of these records it is proposed to give a very rapid outline, referring the Fellows of the Society to the original documents for the various details connected with each. It may be remarked, *in limine*, that in the publications enumerated, there is prefigured nothing short of an entire revolution in the application of instrumental methods to astronomical research. The superb instruments now existing, monuments as they are and ever must be of the genius of a long line of highly gifted men, will not indeed be wholly superseded, but will be mainly valuable as instruments of verification of labours and results obtained, not in painful driblets, but in groups and masses by shorter processes. Astronomers' attention will, in the near future, not be confined to the direct scrutiny of the heavens alone, but to the study of the faithful pictures thereof, taken at will in rapidly occurring successive periods. The consideration of these pictorial views will take the place of laborious catalogues. Potentially they will be such in themselves.

I. *The Harvard Memoir.*—In this memoir Professor Pickering describes a modification of existing forms of camera, consisting mainly of an adjusted compound photographic lens of about eight inches diameter and forty-five inches focal length and controlled by a standard clock, by means of which he can, among other adaptations to be presently described, take pictures of the heavens with considerable facility and sufficiently accurate for maps. With one hour's exposure, stars of a brightness such as those in Peters' and Chacornac's charts can be photographed, and when conveniently enlarged, copies can be printed in permanent ink by some of the many processes known at present. Such maps will be sufficient as charts, but unavailable for the determination of small changes in position. Perhaps these pictorial charts might be supplemented by smaller and more accurate pictures of selected portions of the heavens for purposes of great precision. He entertains the thought that in two observatories, respectively north and south of the Equator, the whole heavens might be charted (to mag. 13 ?) in less than twelve months. Whether a much wider division of labour and a somewhat extended scale in the order of faintness might not be more desirable will probably be best discussed in the proposed convention at Paris in April next.

Of greater originality, and possibly of even greater value, is

the proposition of Professor Pickering to determine the relative brightness of stars, by availing himself of the traces made by stars on the photographic plate while passing, either by unaltered diurnal motion, or instrumentally retarded, across the field of view. In his hands the method assumes a scientific value entirely different from the haphazard estimates of magnitude hitherto put into practice. For the brighter stars (that is, brighter than the eighth magnitude), even when near the Equator, a trace is formed when the camera is stationary; for others less bright the duration of the transit can be regulated as need requires. It is obvious that as the stars approach the Pole, the traces made during a given exposure of the plate become shorter and therefore necessarily are actinised to a greater extent, depending on their length. When the camera has been pointed to the Pole, traces of stars, even of the thirteenth and fourteenth magnitudes, have been photographed with a stationary telescope. A scientific method of estimating relative brightness thus becomes available, it being always premised that a scale of magnitudes, depending on the breadth and length of the traces, has been carefully prepared beforehand. The details of the process must be gathered from the original memoir, and will amply repay the attention of the reader. It should be added that Professor Pickering has successfully applied his method numerically to stars in the *Pleiades*, and to others near the Pole.

The most remarkable and valuable part of Professor Pickering's memoir is that in which he applies the method of trails or traces to the photography of stellar spectra. Hitherto the method of using a narrow slit, supplemented or not by a cylindrical lens, and requiring extreme accuracy in the driving clock, and even then a continued personal vigilance for the manual correction of its irregularities, has proved a most serious drawback in the register of stellar spectra by the aid of photography. By the method of traces the slit, the cylindrical lens, and the painful watching are dispensed with. A prism (of 15°, as used by Professor Pickering) is placed in front of the objective, with its refracting edges horizontal when the star is on the meridian. In this way the star impresses its own spectrum, with the lines thereto peculiar, on the sensitised plate. In the case of the brighter stars the telescope itself remains stationary during the time of exposure; in the case of fainter stars, which require a longer time to impress their traces on the plate, the instrument is driven at any convenient rate, so as to produce in a given time a line of the necessary length. In point of fact, the light of the star itself, by diurnal motion, becomes virtually a line of light, or illuminated slit, which is dispersed into its spectrum by the refracting prism. Professor Pickering, in his memoir, gives an enlarged photographic picture, containing examples of this method applied to the *Pleiades* and some of the brighter stars. The process gives the promise of great facility, and probably great accuracy, amply sufficient for the determi-

nation of the class of a star's spectrum, even in the case of stars of the eighth magnitude. This part of the Harvard labours should not be dismissed without reference to the remarkable *coup d'œil* of the spectra of stars in the *Pleiades*. It is impossible to look at it without the suggestion of a community of origin in the material and formation of this historic group. And the deduction of this cosmical fact is the result of the intelligent labour of a single hour! Altogether this valuable memoir indicates a very distinct advance of the application of photography to astronomical research.

"*Annuaire du Bureau des Longitudes*."—Admiral Mouchez has herein given an interesting account of celestial photography from the time of the well-aimed but unsuccessful attempts of Niépce and Daguerre, in 1839, to the superb results now being achieved at Paris by the brothers Henry. The labours of these latter *savants* are now happily so well known to the astronomical world that an account of them here would be superfluous. One of the most striking features in the photographic enlargements of the plates is the definite roundness and general neatness of the impressions of the stars; features which indicate the remarkable perseverance, or it may be termed the endurance, of the observer in the manual control of the driving clock during the usual exposure of an hour. For any purpose of exact measures this definiteness of outline is indispensable. On some of these plates there are traces of impressions of stars which may probably be regarded as of the sixteenth magnitude. In submitting these photographs to enlargements, and subsequent printing in some permanent material, such as a modification of printer's ink, there is at present an unavoidable loss of the faintest stars, amounting in general to about a magnitude and a half; this will apparently limit printed copies to about the fourteenth magnitude on Pogson's scale, and requires an exposure at present exceeding an hour. We believe it is the present proposition of the Paris astronomers to effect arrangements for the photography of the entire stellar regions to this extent of brightness. This scheme is much more extensive, and perhaps more ambitious, than that proposed by the American astronomer, and instead of its completion at two observatories, in less than a twelvemonth, will require the co-operation of eight or ten at least, extending the labour through four or five years. Indeed, if there be a duplication of the photographic plates—and this seems to be indispensable for securing reliable results—the time occupied in the work and the number of the observers employed must be further extended. But these are points, as already suggested, which must be submitted to the consideration of the convention at Paris, summoned by Admiral Mouchez, in April next.

In the *Annuaire* (page 785) there is a very interesting and instructive plate of highly magnified images of stars impressed on a photographic film. But impressions of this nature, and thus highly magnified, would be far too loose and scattered in

form to admit of micrometric measurement; they greatly differ in appearance from the round and definite and solid-looking formations submitted to measurement at Oxford; nevertheless they do afford a good idea of the mode in which the sensitised material is blackened and deposited. But it should be remembered that this form of actinised deposit was distinctly noticed and described by Bond some thirty years ago.

The direction of the valuable work so ably accomplished at the Paris Observatory will be seen from the following catalogue, taken from the last annual report of that institution. It includes forty-two large plates of the Milky Way and of other regions, viz. the neighbourhood of ε *Lyræ* and of *Vega*, showing after two hours' exposure, stars much feebler than the *debilissima* of Sir J. Herschel, and feebler than the sixteenth magnitude, some of which have probably not been seen before. Clusters in *Hercules* (two plates), in *Ophiuchus*, in *Perseus*, and more than six hundred double or multiple stars; short exposures of groups intended for micrometrical measurement, such as the *Pleiades*, *Præsepe*, and M. 23 *Ophiuchi*.

Mr. Common's Article in the "Nineteenth Century."—It is quite unnecessary to refer to the highly interesting particulars discussed in this paper with all the authority of a master in the art; it will be in the hands of all astronomers interested in the progress of their science.

In even this condensed reference to the advances in Celestial Photography, certainly established by Mr. Common, it is right to add that Mr. Roberts' photographs, which are in the possession of the Society, seem in some respects to have surpassed the *Orion* Nebula of that gentleman, as well as the *Pleiades* Group of MM. Henry.*

The Parallax of 61 Cygni.—So far, the foregoing records refer in the main to what may, without derogation or offence, be termed the pictorial or delineation-side of astronomical photography. We have already stated what the brothers Henry have been able to achieve in the way of celestial charts; possibly even more remarkable results have been accomplished by Mr. Common, who has produced a representation of the *Orion* Nebula surpassing, it may be, in accuracy and in minuteness of detail the united labours of Herschel and Rosse in England, and of Bond and Holden in the United States. One potential only of the new art remained still to be examined; can it be relied on as presenting an amount of accuracy in delicate micrometrical measurement equal to that derived from the use of the Equatoreal Telescope and the Heliometer? In the hands of Bond thirty years ago it did indeed furnish the means of measuring the relative positions of the components of such double stars as he could then photograph; but the important question remains, can it now, in its more important modern development, vie with

* See *Monthly Notices* for January 1887 and Admiral Mouchez's note on p. 813 of the Paris *Annuaire* for 1887.

the Heliometer in the determination of such minute quantities as are discussed in problems connected with Stellar Parallax? In a word, can it be relied on in the conduct of varying measures when they are extended through a series of many months and over hundreds of sensitised plates? There is reason to believe that a reply in the affirmative has been given to this crucial question by the very recent and successful determination of the Parallax of 61 Cygni at the University Observatory in Oxford. No less than eight independent determinations of the relative parallax of the two components of this star, in relation to four faint stars in their neighbourhood, present an accordance that was scarcely to be hoped for anterior to the result. A collateral advantage presented by this method consists in this, that the relative parallax is obtainable not merely in respect of four stars, but in respect of all the other stars upon the photographic plate. In this way the resulting mean becomes not merely relative parallax, but approaches the absolute. In the case of this particular star, the result of the computations is a parallax lying as a mean between those determined by Bessel, Auwers, and Ball.

Dr. Lohse, at Potsdam, has successfully applied the ordinary refracting telescope to the subject of Stellar Photography, and this he has done without separating the lenses of the object glass or the introduction of a subsidiary lens. It is stated that after one hour's exposure of the plate in the proper focal position, the faintest stars visible in the telescope to the eye are distinctly impressed on the photograph.

For information on the valuable and interesting work in Stellar Photography, now in process of execution under the direction of Dr. Gill, the reader is referred to the Report from the Royal Observatory at the Cape of Good Hope, printed in the present number of the *Monthly Notices*.

On taking a general survey of the foregoing records of the potency and astonishing progress of this new application of a recent art, placing the whole starry heavens as a picture in our hands, one's thoughts irresistibly turn to the existence of considerable groups and sections of learned men, who persuade themselves that astronomy, as a science, culminated in the researches of Lagrange and Laplace, and, as an art was worn out in the hands of Bessel and the Herschels. It has been still further affirmed that, amidst the modern developments and activities of other branches of knowledge, astronomy, whether as a science or an art, has ceased to possess human interest. An unprejudiced perusal of the above and similar records is sufficient to indicate the utter unreasonableness of the latter thought. It would be far nearer to the truth to affirm that at the present hour, both as an art and a science, astronomy possesses the elasticity and the hopeful enterprise of robust youth. It would be a still securer belief to rest assured that as long as the human mind retains its experience of the past, and its incentives to curiosity

in respect of the future, no true art can ever culminate, and no true science can become effete. C. P.

The Velocity of Light.

Professor Newcomb has published in the second volume of the important series of astronomical papers prepared for the use of the *American Ephemeris and Nautical Almanac* his measures of the velocity of light made during the years 1880–82. Chapter I. is devoted to an interesting historical account of previous researches on the subject. The method adopted in the present investigation was that of Foucault, with certain modifications, principally in the optical arrangements. The form of the apparatus and the conditions of the problem are fully described in Chapters II. and III.

The revolving mirror consisted of a rectangular prism of polished steel, the vertical faces of which were nickel-plated, and thus formed the surface from which the light was reflected. At each end of the prism a fan-wheel was fixed, and the mirror was driven by an air blast playing upon the opposite side of each wheel. For the fixed mirror, two concave mirrors, each about 40 c.m. in diameter, were used side by side, so as to obviate any slight displacements from a single mirror, and in order to strengthen the return image. The radius of the curvature of the mirror was about 3000 mètres.

In 1880 the locations of the mirrors were at a distance apart of 2550·95 mètres, but in 1881 and 1882 the longer distance of 3721·21 mètres was employed.

All the observations are given in detail, and the results are very fully discussed on the hypotheses (1) that the motion of the revolving mirror is uniform in running; (2) that the figure of the mirror remains invariable; and (3) that the changes in direction of the reflected ray are correctly measured by the angular motion of the receiving telescope around the axis of the revolving mirror. This discussion shows certain systematic differences in the results obtained for each year, the final result depending entirely upon the measures of 1882.

Professor Newcomb gives the concluded velocity of light in vacuo as 299860 kilomètres, with a probable error of ± 30 kilomètres. Combining this result with Nyrén's value of the constant of aberration, the corresponding solar parallax is $8''{\cdot}794$.

To this very important investigation are appended some interesting researches by Mr. Michelson on the velocities of white and coloured light in air, water, and carbon disulphide. The conclusions (which the author advances with great diffidence), are that the velocity of light in carbon disulphide is to that in air as 1·00 to 1·76, with an uncertainty of two units in the second place of decimals; and that orange-red light travels in carbon disulphide from 1 to 2 per cent. faster than greenish-blue light.

The Visual Solar Spectrum in 1884.

The Royal Society of Edinburgh has published during the year (*Transactions*, vol. xxxii. Part III.) a remarkable study of the solar spectrum by the Astronomer Royal for Scotland. The work was undertaken by him with the leading idea of ascertaining whether the spectroscope would offer any evidence as to changes in the absorption of our atmosphere resulting from the great volcanic outbursts of 1883, and especially from that of Krakatoa. The conditions at Edinburgh being unfavourable for work of the kind, Professor Smyth selected as his observing station a country-house called "Kurn Hattin," about two miles to the north of Winchester, and proceeded thither early in June 1884. He was provided with a fine Rowland grating of 14438 lines to the inch, and had attached a recording apparatus of special form to his spectroscope, which enabled him to record with great rapidity the positions of the lines observed. It was his intention to form three complete and independent charts of the entire spectrum, and this design he was enabled to carry out in its entirety, despite very unpropitious weather, by the assistance of Colonel Knight. The results of his observations are given in sixty plates, giving five views of the spectrum, the first two being reproductions of the work of some standard observer for the sake of comparison, the maps of Ångström and Fievez being used for the most part, and the last three the three successive "Winchester" spectra. All are reduced to the same scale, which is not the usual one of wave length, but of wave frequency to the British inch; the wave length expressed in tenth-mètres is however added. The part of the spectrum shown in any plate is clearly and agreeably indicated by tinting it of one homogeneous colour, approximately the average colour of the region; whilst the relative intensities of the dark lines are indicated by variations in their heights. The wave lengths are not absolute determinations, but differential only, Ångström's values for the principal lines being assumed throughout. Even so, however, there are occasionally, as Professor Smyth himself points out, some striking discrepancies between the positions of lines as recorded in the three chartings; but when the unfavourable conditions, under which the greater part of the work was carried out, are remembered, and the great rapidity with which the observations were made—nearly the whole of the second spectrum, extending from A to *h*, and embracing about 7000 lines, having been mapped in three mornings, 1865 lines being laid down in three hours—the general accord between the three independent maps is very remarkable. Perhaps not the least important result of the work will have been to

show how rapidly a detailed chart of the entire visible spectrum can be formed when a suitable recording apparatus is employed.

With regard to the immediate purpose of the charts, the principal result Professor Smyth deduces from them is, that the visual solar spectrum in 1884 showed a marked general dulling at the two ends, the red and violet, "such as should arise from the upper air, being at that time overcharged with opaque dusty particles." The evidence for the existence of fresh atmospheric lines was much less satisfactory, although a strong line, wave length 4733 tenth-mètres, was repeatedly observed at Winchester, which is not shown on Fievez's chart. The repetition of such a survey of the spectrum as Professor Smyth has here carried out, at intervals of two or three years apart, would probably lead to the detection of changes in it which could scarcely fail to be instructive. In the meantime, Professor Smyth has supplied a valuable record of its appearance in the summer of 1884.

E. W. M.

Papers read before the Society from February 1886 *to February* 1887.

1886.

Mar. 12. Phenomena of the satellites of *Jupiter* and *Saturn*, and occultations of stars by the Moon, observed at Mr. Edward Crossley's Observatory, Bermerside, Halifax, in the year 1885, with the $9\frac{1}{3}$-inch Cooke Refractor. J. Gledhill.

Occultation of *Aldebaran*, 1886, Jan. 16. Professor R. S. Ball.

Occultations observed at Beloit, Wisconsin, in 1884–85. J. Tatlock.

On the orbit of 40 (o^2) *Eridani*. J. E. Gore.

The great shower of Andromedes, 1885. T. W. Backhouse.

Some new red and orange-red stars. Rev. T. E. Espin.

Observation of the conjunction of *Saturn* and μ *Geminorum*. J. Tebbutt.

Additional remarks on the periodic time of α *Centauri*. E. B. Powell.

Occultations of stars by the Moon and phenomena of *Jupiter's* satellites observed at Stonyhurst in the year 1885. Rev. S. J. Perry.

The new star in *Orion*, photometrically and spectroscopically observed at the Oxford University Observatory. Professor C. Pritchard.

Observations of comets *d* 1885 (Fabry), and *e* 1885 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

Note on some recently published spectroscopic observations. E. W. Maunder.

Observations of the new star in *Andromeda*, made at Mr. Wigglesworth's Observatory with 15·5-inch Cooke Refractor. J. G. Lohse.

April 9. Note on the radiation of meteors. W. F. Denning.

On some suggested improvements in the practical working of M. Loewy's new method of determining the elements of astronomical refraction. David Gill.

On the orbit of α *Centauri*. E. B. Powell.

April 9. Observations of the phenomena of *Jupiter's* satellites, made at the Adelaide Observatory with the 8-inch Cooke Equatorial in the year 1885. Communicated by C. Todd.

The magnitude of η *Argûs* in March 1886. W. H. Finlay.

On the protuberances visible in the spectrum with a narrow slit. E. L. Trouvelot.

Observations of occultations of the stars by the Moon, 1884–85, and of the IVth satellite of *Jupiter*, 1885, made at the Radcliffe Observatory, Oxford. Communicated by E. J. Stone.

On the semi-diameter of *Venus*. W. G. Thackeray.

The nebulæ in the *Pleiades*. A. A. Common.

Note on the observations for coincidence of the collimators through the cube of the Transit Circle at the Royal Observatory, Greenwich. H. H. Turner.

Observations of Comets *d* 1885 (Fabry), and *e* 1885 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

May 14. Note on M. Trouvelot's paper on protuberances visible in the spectrum with a narrow slit. E. W. Maunder.

Introduction to a catalogue of the colours of 1730 stars. W. S. Franks.

Observations of the companion of *Sirius* made at the Dearborn Observatory, Chicago. Prof. G. W. Hough.

Jupiter's third satellite in transit, April 11, 1886. W. F. Denning.

Observations of the new star in *Orion*. J. E. Gore.

The meteor shower of Halley's Comet. W. F. Denning.

On the proper motion of twenty-nine telescopic stars. J. L. E. Dreyer.

Note on a remarkable sun spot. B. J. Hopkins.

Observations of Comets *d* 1885 (Fabry), *e* 1885 (Barnard), and *a* 1886 (Brooks), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

The fourth satellite of *Jupiter* during superior conjunction on the night of April 5, 1886. E. J. Spitta.

Comparisons of certain southern star catalogues. A. M. W. Downing.

June 11. Micrometric observations of Nova *Andromedæ*, made at the Dunsink Observatory. Sir R. S. Ball.

Observations of the satellites of *Saturn* and *Mars*, and of the companion of *Sirius*, made at the U.S. Naval Observatory, Washington. Professor Asaph Hall.

On the orbit of ζ *Sagittarii*. J. E. Gore.

On Delaunay's method of calculating the terms of long period in the motion of the Moon. E. Neison.

June 11. Observations of Comet Fabry (*d* 1885), made at Grahamstown, Cape of Good Hope. L. A. Eddie.

On Kepler's problem. R. Bryant.

Observations of comet *a* 1886 (Brooks), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

On the asserted foreshortening of the inner side of the penumbra of spots when near the Sun's limb. Rev. F. Howlett.

On the superiority of zinc and steel pendulums. T. Buckney.

Ephemeris of the satellites of *Saturn*, 1886–87. A. Marth.

The northern hemisphere of *Mars*. N. E. Green.

On a remarkable instance of the detection of distortion in a photographic film, measured for the purpose of stellar parallax. Professor C. Pritchard.

Supplementary measures of the magnitudes of a zone of stars near the equator for reference as standards of magnitude in lieu of *Polaris*. Professor C. Pritchard.

Note with respect to the invention of the achromatic telescope. A. C. Ranyard.

Nov. 12. Observations of the variable star *R Carinæ* from Sept. 1883 to April 1886. J. Tebbutt.

Observations of Comets *d* 1885 (Fabry), *e* 1885 (Barnard), *c* 1886, and I. 1886 (Brooks), made at the Sydney Observatory. Communicated by H. C. Russell.

Observations of Comets 1877, I., II., III., VI.; 1880, III.; 1882, III.; and 1884, III., made at the Dun Echt Observatory with the 15-inch Refractor. Dr. R. Copeland.

Sextant observations of Fabry's Comet. Capt. J. Campbell, and Capt. D. S. Cromarty.

Observation of *Calliope*, made at the Observatory, Düsseldorf. [Extract from a letter to Mr. Stone.] Dr. R. Luther.

Ephemeris of the satellite of *Neptune*, 1886 87. A. Marth.

On the orbit of Σ 1757. J. E. Gore.

A reply to Mr. Neison's strictures on Delaunay's method of determining the planetary perturbations of the Moon. G. W. Hill.

On the orbit of Comet II., 1883, discovered by Mr. Ross. Lieut.-Gen. J. F. Tennant.

On the determination of the Radius Vector in the absolute orbit of the planets. Dr. H. Gyldén.

Observations of the phenomena of *Jupiter's* Satellites made at Windsor, New South Wales, in the year 1886. J. Tebbutt.

Nov. 12. Newall's occultor. R. S. Newall.
Distribution of Meteor Streams. W. F. Denning.
Note on the star γ *Equulei*. G. Knott.
Reply to certain questions raised before the Royal Astronomical Society at the meeting on 1886, March 12, concerning the matter detailed in a paper entitled "Bright lines in stellar spectra." O. T. Sherman.
Note on Photographs of Stars in *Cygnus*, taken in August 1886. Isaac Roberts.
Note on two photographs of the Nebulæ in the *Pleiades*, taken in October 1886. Isaac Roberts.
Ephemeris for physical observations of *Jupiter*, 1887. A. Marth.
On evidence with respect to the form of the area of the heavens from which the meteors of November 27, 1885, appeared to radiate. A. C. Ranyard.
Observations of Comet *f* 1886 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.
Bands observed in the spectra of sun spots at Stonyhurst Observatory. Rev. A. Cortie.
Observations of Comets made at Mr. Wigglesworth's Observatory with the 15·5-inch Cooke Refractor. J. G. Lohse.

Dec. 10. Formulæ for binary stars. J. E. Gore.
Observations of Comets Winnecke and Finlay, 1886, made with the 11½-inch equatorial and filar micrometer at the Sydney Observatory. Communicated by H. C. Russell.
Ephemeris of the satellites of *Uranus*, 1887. A. Marth.
Second supplement to Sir J. Herschel's general catalogue of nebulæ and clusters of stars. J. L. E. Dreyer.
Note on an erratic meteor. B. J. Hopkins.
On Hartwig's Nova *Andromedæ*. Dr. R. Copeland.
Mr. Sherman's observations of bright lines in stellar spectra. E. W. Maunder.
Observations of Comet *f* 1886 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

Jan. 14. Spectroscopic observations of the motion of stars in the line of sight made at the Temple Observatory, Rugby. G. M. Seabroke.
On the best device for revolving a dome. D. P. Todd.
Meteors with curved paths. W. F. Denning.
A new variable star in *Puppis*. A. S. Williams.
On the orbit of 14 (*i*) *Orionis* (OΣ 98). J. E. Gore.
Occultation of γ *Virginis*, 1886, Dec. 18. F. C. Penrose.
Photographs of nebulæ in *Orion* and in the *Pleiades*. Isaac Roberts.

Jan. 14. Note on the electric illumination of the Armagh Refractor. J. L. E. Dreyer.

Occultation of *Aldebaran*, 1887, Jan. 6. Rev. S. J. Johnson.

Observations of Comet *f* 1886 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

Sextant observations of Comets Fabry and Barnard, 1886. Capt. W. G. Browne and Capt. W. Randall.

On the variability of the spectrum of γ *Cassiopeiæ*. Dr. R. Copeland.

Note on an application of photography to the determination of stellar parallax. Professor C. Pritchard.

Observations of the Moon made at the Radcliffe Observatory, Oxford, during the year 1886, and a comparison of the results with the tabular places from Hansen's Lunar Tables. E. J. Stone.

Mean Right Ascensions of *Polaris*, *Cephei* 51 (Hev.), δ *Ursæ Minoris* and λ *Ursæ Minoris* for the year 1887, from the Radcliffe Observations of the years 1880 to 1886. E. J. Stone.

Spectroscopic results for the motions of stars in the line of sight obtained at the Royal Observatory, Greenwich, in the year 1886. No. X. Communicated by the Astronomer Royal.

Observations of occultations of stars by the Moon, and of phenomena of *Jupiter's* Satellites, made at the Royal Observatory, Greenwich, in the year 1886. Communicated by the Astronomer Royal.

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Munich, Royal Observatory.
Naples, Academy of Sciences.
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ADDRESS

Delivered by the President, Mr. J. W. L. Glaisher, on presenting the Gold Medal of the Society to Mr. G. W. Hill.

The Council have awarded the Gold Medal to Mr. George William Hill for his researches upon the Lunar Theory; and it now becomes my duty to lay before you the grounds of this award.

The investigations of Mr. Hill's which the Council have had principally in view are contained in the memoir "On the Part of the Motion of the Lunar Perigee, which is a Function of the Mean Motions of the Sun and Moon," which was published by him ten years ago at Cambridge, Mass. The merits of Mr. Hill's treatment of this question are such, that, even if this memoir stood by itself as his sole contribution to physical astronomy, the Council would have felt themselves justified in recognising its value by the highest mark of appreciation which it is in their power to confer. Mr. Hill's object in this memoir is to determine with absolute accuracy the motion of the Moon's perigee, on the assumption that the Sun's orbit has no eccentricity, that the Moon's motion takes place in the plane of the ecliptic, and that the eccentricity of the Moon's orbit is indefinitely small: in other words, to determine an absolutely accurate value of that part of c which depends upon m alone.

It will be remembered that this quantity c, which expresses the mean motion of the Moon's perigee, has played an important part in the early history of the theory of gravitation. Newton proved a general proposition from which it follows that the disturbing action of the Sun necessarily produces a continual advance of the Moon's perigee; and he gave a numerical example which has been generally regarded as his calculation of the theoretical amount of this advance in the case of the Moon.* The mean monthly progression obtained in this example

* Lib. I., Sect. ix., Prop. xlv., Cor. 2. The concluding words "Apsis lunæ est duplo velocior circiter" have been quoted in support of the view that the motion of the lunar apsides is the question considered in this corollary. These words were, however, intended to have exactly the opposite meaning. This can be shown by comparing the three editions of the *Principia*; further confirmation is also afforded by certain papers lately found by Professor Adams in the Portsmouth collection of Newton manuscripts.

is 1° 31′ 28″, whereas the observed monthly progression of the Moon is about double this amount. This discrepancy formed one of the chief impediments to the acceptance of the Newtonian system, and an interval of sixty years elapsed before theory and observation were brought into agreement. This was effected by Clairaut, who was on the point of publishing a new hypothesis with respect to the law of gravitation, when it occurred to him to extend the approximation to the third order. He found that the numerical value of the new term was nearly as great as that of the term of the second order. The supposed Newtonian value of $1-c$ was $\frac{3}{4}m^2$, and Clairaut's additional term was $\frac{225}{32}m^3$; amounting to about $\frac{7}{10}$ of the previous term. Thus the circumstance which had for some time seemed almost fatal to the Newtonian theory became one of its strongest confirmations.

The series of which the first two terms were calculated by Newton and Clairaut has been continued by Delaunay as far as the term involving m^9. The progression of the terms is such as we might anticipate from the first two; the coefficients increase rapidly; and, though the smallness of m causes the terms to diminish, their rate of convergence is very slow.

The problem which Mr. Hill set before himself for solution was the exact determination of the numerical value of the quantity represented by this series. The development in powers of m, besides being extremely difficult and laborious to obtain, was from its nature ill adapted for the calculation of c with all the precision that could be desired. Mr. Hill accordingly had recourse to an entirely different method of obtaining the numerical value of this quantity.

Starting with the general equations of motion, he finds the differential equations which determine the inequalities having the first power of the lunar eccentricity as a factor. By a remarkable series of analytical transformations, the solution of these differential equations is made to depend upon that of a single differential equation of the peculiarly simple and elegant form

$$\frac{d^2w}{d\tau^2} + \Theta w = 0,$$

where τ denotes the mean angular distance between the Sun and Moon, and Θ can be developed in a periodic series of the form

$$\Theta_0 + \Theta_1 \cos 2\tau + \Theta_2 \cos 4\tau + \&c.$$

If Θ_1, Θ_2, &c. are to a considerable degree smaller than Θ_0, an approximate solution of the equation is

$$w = Ke^{ic\tau} + K'e^{-ic\tau},$$

where i denotes $\sqrt{-1}$, K and K′ are arbitrary constants, and c denotes the square root of Θ_0. When the additional terms are

taken into account, the effect is to modify this value of c, and also to add to w new terms of the form

$$e^{\pm i(c+2p)\tau}.$$

We may, therefore, take as a particular integral

$$w = \Sigma_p b_p e^{i(c+2p)\tau};$$

and by substituting this value of w in the differential equation, we obtain an infinite system of algebraical equations, each consisting of an infinite number of terms. This system of equations suffices to determine the ratios of all the coefficients b_1, b_2, &c., to one of them, as b_0, and also the value of c, the ratio of the synodic to the anomalistic month.

If from these equations we eliminate all the b's, we obtain a symmetrical determinant of an infinite order involving c, which, when equated to zero, determines this quantity. This equation Mr. Hill writes

$$\mathfrak{D}(c) = 0.$$

A first approximation to the value of c is $\sqrt{\Theta_0}$; a second and much more accurate approximation is given by

$$c = \sqrt{1 + \sqrt{(\Theta_0 - 1)^2 - \Theta_1^2}}.$$

This very simple expression for an approximate value of the motion of the Moon's perigee is obtained by neglecting quantities of the order m^5 in the determinantal equation $\mathfrak{D}(c) = 0$. The numerical values of Θ_0 and Θ_1 are

$$\Theta_0 = \quad 1{\cdot}1588439$$
$$\Theta_1 = -0{\cdot}0570440,$$

and by substituting these values in the above expression for c we find

$$c = 1{\cdot}0715632$$

whence

$$1 - c = 1 - c(1 - m) = 0{\cdot}008591.$$

This is about $\frac{1}{60}$ in excess of the value 0·008452 given by observation; the difference being mainly due to the neglect of the inclination of the lunar orbit.*

* Mr. Hill has also given the following curious formula, which is obtained by neglecting quantities of the order m^7:

$$\tan\theta = \frac{\pi\Theta_1^2}{4\sqrt{\Theta_0}(\Theta_0 - 1)},$$

then c is given by the equation

$$\cos \pi c = \frac{\cos(\pi\sqrt{\Theta_0} - \theta)}{\cos\theta}.$$

This formula, though it involves the same coefficients Θ_0 and Θ_1 as the approximate formula given in the text, is much more exact. It gives $1 - c = 0{\cdot}00857210$, which is correct to the sixth decimal. See the reprint of Mr. Hill's paper in the *Acta Mathematica*, vol. viii. (1886), p. 28.

In order to deduce a perfectly accurate value of c from the equation $\Delta(c) = 0$, Mr. Hill proceeds to consider the nature of the roots of this equation. He points out that if it is satisfied by $c = c_0$ it must necessarily be satisfied also by all quantities of the form $\pm (c_0 + 2p)$, p being an integer; and he is thus led to put

$$\Delta(c) = A\{\cos(\pi c) - \cos(\pi c_0)\}$$

The constant A is next determined, and the determinant $\Delta(c)$ is replaced by a new determinant $\nabla(c)$, derived from it by the equation

$$\nabla(c) = \frac{1}{A}\Delta(c)$$

so that

$$\nabla(c) = \cos(\pi c) - \cos(\pi c_0).$$

This equation is true identically. Putting $c = 0$, and subtracting, we thus find

$$\cos(\pi c) = 1 - \nabla(0),$$

as the subscript zero may now be omitted. This very remarkable equation is equivalent to $\Delta(c) = 0$, and gives by its solution the value of c, which we are seeking; the particular root to be chosen being that to which $\sqrt{\Theta_0}$ is a first approximation.

Mr. Hill makes still one further change in order to replace $\nabla(0)$ by a determinant in which all the terms in the principal diagonal shall be unity. Denoting this new determinant by $\square(0)$, the final form of the equation giving c is expressed in the form:

$$\frac{\sin^2(\frac{1}{2}\pi c)}{\sin^2(\frac{1}{2}\pi\sqrt{\Theta_0})} = \square(0),$$

where $\square(0)$ denotes the very elegant determinant

$$\begin{vmatrix}
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdots, & 1, & -\frac{\Theta_1}{4^2-\Theta_0}, & -\frac{\Theta_2}{4^2-\Theta_0}, & -\frac{\Theta_3}{4^2-\Theta_0}, & -\frac{\Theta_4}{4^2-\Theta_0}, & \cdots \\
\cdots, & -\frac{\Theta_1}{2^2-\Theta_0}, & 1, & -\frac{\Theta_1}{2^2-\Theta_0}, & -\frac{\Theta_2}{2^2-\Theta_0}, & -\frac{\Theta_3}{2^2-\Theta_0}, & \cdots \\
\cdots, & -\frac{\Theta_2}{0^2-\Theta_0}, & -\frac{\Theta_1}{0^2-\Theta_0}, & 1, & -\frac{\Theta_1}{0^2-\Theta_0}, & -\frac{\Theta_2}{0^2-\Theta_0}, & \cdots \\
\cdots, & -\frac{\Theta_3}{2^2-\Theta_0}, & -\frac{\Theta_2}{2^2-\Theta_0}, & -\frac{\Theta_1}{2^2-\Theta_0}, & 1, & -\frac{\Theta_1}{2^2-\Theta_0}, & \cdots \\
\cdots, & -\frac{\Theta_4}{4^2-\Theta_0}, & -\frac{\Theta_3}{4^2-\Theta_0}, & -\frac{\Theta_2}{4^2-\Theta_0}, & -\frac{\Theta_1}{4^2-\Theta_0}, & 1, & \cdots \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot
\end{vmatrix}$$

In the lunar theory the quantity Θ_p is of the $2p^{\text{th}}$ order. Mr. Hill, with great analytical skill developes this determinant as

far as terms of the twelfth order. It is with reluctance that I abstain from reproducing the remarkable expression which he obtains. It occupies eight lines, and consists of terms of the fourth order, the eighth order, and the twelfth order. It is exactly the same result as would be obtained if, starting with the equation $\square(c) = 0$, and assuming $c = \sqrt{\Theta_0}$ as a first approximation, we expanded the function $\sin^2(\frac{1}{2}\pi c)$ in ascending powers and products of the coefficients Θ_1, Θ_2, &c.

Passing now to numbers, Mr. Hill puts

$$n = 17325594''{\cdot}06085$$
$$n' = 1295977''{\cdot}41516$$

and deduces the value of $\Theta_0, \Theta_1, \ldots \Theta_7$ to 15 places of decimals, and by substituting these values in his expression for $\square(0)$ he obtains finally

$$c = 1{\cdot}07158\ 32774\ 16012,$$

whence

$$1 - c = 0{\cdot}00857\ 25730\ 04864.$$

By a process of substitution in the original equations a verification of this value of c is afforded.

It is interesting to compare Mr. Hill's value with the value given by Delaunay's expression in powers of m, viz.:

$$1 - c = \frac{3}{4}m^2 + \frac{225}{32}m^3 + \frac{4071}{128}m^4 + \frac{265493}{2048}m^5 + \frac{12822631}{24576}m^6 + \frac{1273925965}{589824}m^7 + \frac{71028685589}{7077888}m^8 + \frac{3214588270774 1}{679477248}m^9.$$

Using the values of n and n' given above, the numerical values of the terms of this series are

m^2	0·00419 6429	m^6	0·00009 1395
m^3	0·00294 2798	m^7	0·00002 8300
m^4	0·00099 5700	m^8	0·00000 9836
m^5	0·00030 3577	m^9	0·00000 3468

giving 0·00857 1503 as the value of $1 - c$.

By comparing this value with Mr. Hill's it appears that the sum of the remainder of Delaunay's series is 0·0000 1070, which is rather less than might be inferred by induction from the terms of the series itself. In spite of the labour expended by Delaunay in computing eight terms of this series, the result does not suffice to give correctly the first four significant figures of $1 - c$. On the other hand, in Mr. Hill's process, the highest terms included in the calculation of the expression for $\square(0)$ are only of the twelfth order, and yet they suffice to give c correctly to the fifteenth decimal. As well as can be judged by induction, it

would be necessary, Mr. Hill thinks, to prolong Delaunay's series as far as m^{27} in order to obtain an equally precise result.

I am sensible that a presidential address does not in general afford a suitable opportunity for mathematical exposition; but I have felt that on the present occasion the novelty and intrinsic interest of the mathematical methods employed justify me in the attempt I have made to give a brief sketch of the remarkable investigation by which Mr. Hill has arrived at his numerical value of c. It will be observed that the problem of the determination of this quantity is attacked entirely *de novo*, from first principles, by a peculiar analytical method devised for this especial purpose. The object is to obtain the numerical value of that part of c which depends upon m only; and this object is attained with a degree of precision that sets the problem at rest for ever.

The mathematical process is very peculiar. Not only is it quite different from any of the methods with which the lunar theory is associated, but it even displays novelty from the point of view of the pure mathematician. I am not aware that actual use has ever been previously made of an infinite determinant in any of the applications of mathematics, or that the development of such a determinant (by proceeding outwards from its central constituent, as it were) has ever been the subject of mathematical investigation. One cannot admire too highly the courage and skill with which Mr. Hill has dealt with the new mathematical questions to which his methods have led him. Not only has he availed himself of the modern instruments which the advance of mathematics had placed within his reach, but he has successfully grappled with the novel mathematical difficulties which have accompanied their use. The calculation of the determinants formed from the 3^2, 5^2, 7^2, &c. constituents symmetrically disposed with respect to the central constituent of an infinite determinant, and the consideration of the convergency of these determinants, are questions of mathematical interest which are well deserving of study on their own account, apart from the practical applications in which, as Mr. Hill has shown, the results of such investigations are required.

Although the memoir of Mr. Hill's to which I have so far confined myself was the first in order of publication of his papers on the Lunar Theory, its true chronological place is subsequent to his "Researches on the Lunar Theory," which appeared in the first volume of the "American Journal of Mathematics" (1878). In the calculation of the quantities Θ_0, Θ_1, Θ_2, &c. (which depend only upon the case of no eccentricities), Mr. Hill derived his numerical data from an investigation of his own to be subsequently published. This investigation is contained in the "Researches," which may be regarded as introductory to the memoir relating to the motion of the perigee.

At the beginning of the "Researches" Mr. Hill divides the periodic developments of the lunar co-ordinates into classes of

terms, and proposes to treat the following five classes of inequalities:

1. Those which depend only on the ratio of the mean motions of the Sun and Moon.
2. Those which are proportional to the lunar eccentricity.
3. Those which are proportional to the sine of the lunar inclination.
4. Those which are proportional to the solar eccentricity.
5. Those which are proportional to the solar parallax.

He also promises a general method by which these investigations may be extended so as to cover the whole ground of the Lunar Theory.

Only two chapters of the "Researches" were published: the first relates to the general differential equations of motion, and the second to the first of the five classes of inequalities mentioned above. The memoir on the motion of the perigee belongs to the second class; so that we are in possession of Mr. Hill's general methods and their application to two out of the five classes of inequalities.

Passing over Mr. Hill's able discussion of the general equations of motion, I proceed to give a brief sketch of the analytical method by which he treats the first two classes of inequalities.

If the axis of x rotate with uniform angular velocity n', so as always to pass through the Sun, the differential equations of motion in the ordinary form are

$$\frac{d^2x}{dt^2} - 2n'\frac{dy}{dt} + \left(\frac{\mu}{r^3} - 3n'^2\right)x = 0,$$

$$\frac{d^2y}{dt^2} + 2n'\frac{dx}{dt} + \frac{\mu}{r^3}y = 0.$$

Mr. Hill transforms these equations as follows:

Denoting $\sqrt{(-1)}$ by i, let

$$\nu = n - n',$$

$$m = \frac{n'}{\nu}, \quad \kappa = \frac{\mu}{\nu^2};$$

also let

$$\tau = \nu(t - t_0), \qquad \zeta = e^{i\tau},$$

and put

$$u = x + iy, \qquad s = x - iy,$$

$$D = -i\frac{d}{d\tau} = \zeta\frac{d}{d\zeta};$$

so that

$$D\zeta^p = p\zeta^p;$$

then u and s satisfy the differential equations :

$$\left\{D^2+2mD+\tfrac{3}{2}m^2-\frac{\kappa}{(us)^{\frac{3}{2}}}\right\}u+\tfrac{3}{2}m^2s=0,$$

$$\left\{D^2-2mD+\tfrac{3}{2}m^2-\frac{\kappa}{(us)^{\frac{3}{2}}}\right\}s+\tfrac{3}{2}m^2u=0,$$

each of which may of course be derived from the other by changing the sign of i.

These equations determine rigorously all the parts of the lunar co-ordinates which depend only on the ratio of the mean motions of the Sun and Moon and the lunar eccentricity.

Now let

$$u=\Sigma a_p\zeta^{2p+1},$$

$$s=\Sigma a_{-p-1}\zeta^{2p+1},$$

p having all integral values from $+\infty$ to $-\infty$.

The most simple method of obtaining the coefficients a_p is by substituting these values of u and s in the differential equations and equating coefficients. The presence of the factor $-\frac{\kappa}{(us)^{\frac{3}{2}}}$ is a great additional source of complication in carrying out this process, and it is therefore desirable to eliminate it. This Mr. Hill effects by means of a first integral of the differential equations, and he at length obtains, as the final form of the equations to be employed,

$$D^2(us)-Du\,.\,Ds-2m(uDs-sDu)+\tfrac{9}{4}m^2(u+s)^2=C,$$

$$D(uDs-sDu-2mus)+\tfrac{3}{2}m^2(u^2-s^2)\qquad\qquad=0.$$

By substituting the values of u and s in these differential equations, a system of algebraical equations connecting the a's is obtained from which they may be determined either numerically or algebraically in terms of m.

It will be noticed that the differential equations in this final form are such that in no case is it necessary to multiply together more than two infinite series.

The system of algebraical equations obtained by equating coefficients is infinite in number, and each equation contains an infinite number of terms involving the products of two a's.

It is found that a_p is of the $2p^{\text{th}}$ order with respect to m ; and, in solving the equations, only the terms of lowest order are in the first instance retained. The equations thus curtailed give the first four terms of the expansions in powers of m of a_1, a_{-1}, a_2, a_{-2}, &c. Thus a_1 and a_{-1} are affected with errors of the sixth order ; a_2 and a_{-2} with errors of the eighth order, and so on.

One of the great advantages of the method consists in the ease and rapidity with which the approximations can be extended ; for we have only to return to the original curtailed equations and augment each of them by the terms necessary to carry the

approximation four orders higher; we then substitute in the new terms the values obtained from the first approximation, and in the old we determine what changes are produced by employing the more exact values instead of the first approximations. A repetition of this process carries the approximation four orders higher still, and so on.

Mr. Hill gives in full the equations which determine the a's correctly to quantities of the thirteenth order inclusive; * and he deduces from them the expansions of

$$\frac{a_{\pm 1}}{a_0}, \ldots \frac{a_{\pm 4}}{a_0}.$$

in powers of m as far as m^9.

From these expansions the values of $r \cos v$ and $r \sin v$, as series proceeding by cosines and sines of multiples of 2τ, are easily deduced by means of the equations

$$r \cos v = \Sigma a_p \cos 2p\tau$$
$$r \sin v = \Sigma a_p \sin 2p\tau,$$

the summations extending to infinity both ways. The coefficients in these series are given as far as the ninth order inclusive in powers of $\mathfrak{m}$, where

$$\mathfrak{m} = \frac{m}{m - \frac{1}{3}m}.$$

Not only does Mr. Hill give these coefficients in a literal form, which he afterwards reduces to numbers, but he gives also the direct numerical calculation, employing numerical values from the outset in the equations of condition. This latter method is found to be, as we should suppose, far less laborious than the literal development of the coefficients in powers of a parameter.

The series given by previous mathematicians are unsuitable for the determination of the motion of satellites having long periods of revolution about their primaries; and Mr. Hill is accordingly led to apply his method, which is available in such cases, to the exact determination of the expressions for $r \cos v$ and $r \sin v$ in terms of τ when $m = \frac{1}{10}, \frac{1}{9}, \frac{1}{8}, \ldots \frac{1}{3}$. For moons of much longer lunations the method is not practicable, and it is necessary to resort to mechanical quadratures. The motion is

* The final differential equations only suffice to determine the ratios of the a's to any one of themselves, as a_0. For the actual determination of a_0 in terms of μ and n recourse must be had to one of the original differential equations, and in this way the value of a_0, viz.

$$a_0 = \left(\frac{\mu}{n^2}\right)^{\frac{1}{3}} \left[1 - \tfrac{1}{6}m^2 + \tfrac{1}{3}m^3 + \tfrac{407}{2304}m^4 - \&c. \right]$$

is determined as far as the term involving m^9 inclusive. It is from the values of the coefficients a_p, which depend upon m alone, that the values of Θ_0, Θ_1, Θ_2, &c., which were required in finding the motion of the perigee, were derived by Mr. Hill.

determined in this manner in the cases of $m = 2$ and $m = 1{\cdot}78265$. The latter value of m corresponds to a lunar orbit (relative to the moving axes) having cusps at the points of quadratures.

Brief as has necessarily been the preceding account of the mathematical processes employed by Mr. Hill, I hope that it has been sufficient to give an idea of their character. It is not often that the points of novelty in an application of mathematics to a well-known problem in one of the older sciences are so distinctive as to admit of explanation within a moderate compass. The present investigation is so exceptional in this respect that I have ventured to reproduce the main lines of the mathematical procedure.

Two obvious deviations from established custom at once attract attention: first, the use of rectangular instead of polar coordinates; and secondly, the introduction of the imaginary quantity i.

With regard to the choice of coordinates, it is known that in the elliptic theory the rectangular coordinates of a planet relative to a central body can be developed in series of sines and cosines, in which the coefficients are Besselian functions, although the longitude and latitude are far from having such simple expressions, and in fact are not even finitely expressible in terms of Besselian functions. If this be true in the elliptic theory, how much more likely, Mr. Hill asks, is a similar result to be true when the complexity of the problem is increased by the consideration of the disturbing forces? Thus there is reason to believe that the coefficients of the periodic terms in the developments of the rectangular coordinates are less complex functions of their parameters than in the case of polar coordinates. Another important advantage is afforded by the fact that when expressed in rectangular coordinates the differential equations assume purely algebraic forms, while in polar coordinates they involve circular functions.

The quantity i is used in order to avoid the multiplications of series of sines and cosines, and to reduce all the quantities to an algebraic form. It is at once apparent that the choice of e^{ri} or ζ as independent variable greatly simplifies the expression of the series and the analysis in general. Having had occasion myself, in a very different branch of mathematics, to multiply together infinite series of sines and cosines, I have found the advantage of making a similar substitution, and I can bear testimony to the analytical simplicity and regularity produced in such processes by the substitution of

$$\Sigma_{-\infty}^{\infty} A_p z^p \quad \text{and} \quad \frac{1}{i} \Sigma_{-\infty}^{\infty} B_p z^p$$

for

$$A_0 + 2\Sigma_1^{\infty} A_p \cos 2p\theta \quad \text{and} \quad 2\Sigma_1^{\infty} B_p \sin 2p\theta$$

A_{-p} and B_{-p} being supposed equal to A_p and $-B_p$ respectively.

It may be remarked that the vector u or $x+iy$ is a symbol to which a clear conception is now attached, and also that in the equation

$$x+iy=\Sigma a_p \zeta^{2p+1}$$

the quantities a_0, a_1, a_{-1}, &c. are the radii of actual epicycles. The geometrical picture which this equation represents is that of a pure epicyclic system.

Mr. Hill employs the parameter m, which is equal to $\frac{m}{1-m}$, in place of m. Although m is slightly larger than m it is found that in the series proceeding by powers of m the coefficients are much smaller than in the case of those proceeding by powers of m. and that the series converge more rapidly. The quantity m, which has been mentioned above, was specially determined in order to render the series giving the a's as convergent as possible.

The superiority of the expansions in powers of m, both in convergence and simplicity of coefficients, is evident by comparing the values of $\frac{a_1+a_{-1}}{a_0}$ and $\frac{a_1-a_{-1}}{a_0}$, which when expressed in powers of m assume the forms

$$-\{m^2+\tfrac{1}{2}m^3-\tfrac{2}{3}m^4+\tfrac{1}{36}m^5-\&c.\}$$

and

$$\tfrac{11}{6}m^2+\tfrac{5}{4}m^3+\tfrac{5}{72}m^4-\tfrac{11}{36}m^5+\&c.$$

respectively; the corresponding series, as given by Plana and Delaunay, being

$$-\{m^2+\tfrac{19}{6}m^3+\tfrac{131}{18}m^4+\tfrac{383}{27}m^5+\&c.\}$$

and

$$\tfrac{11}{8}m^2+\tfrac{59}{12}m^3+\tfrac{893}{72}m^4+\tfrac{2855}{108}m^5+\&c.$$

With regard to the general question of parameters, it is pointed out that the large numerical coefficients which occur in Delaunay's expansions are probably due to the choice of m as parameter, and that they might be very much diminished if a more suitable parameter were employed. Further, it is not necessary to use the same parameter throughout, and it may well happen that different parameters may be advantageously employed in the investigation of different classes of inequalities. Examples of the extraordinary increase of convergence which can be affected by a change of parameter are afforded by logarithmic series, and, in a much more striking form, by the various expansions of the elliptic functions. Mr. Hill, however, gives it as the result of his experience that no useful results are obtained by experimenting with the present known developments, and that in every case the proper parameter must be derived from *à priori* considerations suggested by the course of the integration.

Passing now to general considerations, it will be noticed that Mr. Hill obtains the integrals of his differential equations by the method of indeterminate coefficients. This is the method which would seem to offer the best chance of discovering the law of the series. A further advantage of this method, which is not possessed by Delaunay's, is that it affords either the numerical values of the coefficients or the literal development in powers of a parameter.

Of all the general methods of treating the Lunar Theory as a whole, Delaunay's is by far the most elegant and complete, and is likely to become the classic method in this subject. When, however, the object is to investigate only a certain class of inequalities, it is not without its disadvantages; for example, even if we only desire to obtain the inequalities whose coefficients depend solely upon m, we are nevertheless obliged to develop the disturbing function R to all powers of e. Again, in Delaunay's method, the number of variables is doubled in order that all the differential equations may be of the first order; but when the coefficients are determined by direct substitution in the differential equations their order is immaterial. The two main characteristics which distinguish Mr. Hill's general analytical treatment of the lunar theory are the expression of the equations in terms of the coordinates instead of in terms of the elements, and the diminution of the number of variables and differential equations at the expense of increasing the order of the latter.

Immediately after the publication of Mr. Hill's first memoir (on the motion of the Moon's perigee), Professor Adams communicated a paper to the *Monthly Notices* (vol. xxxviii., p. 43), in which, after bearing testimony to the high merits of Mr. Hill's investigation, he mentions that he has been led to dwell thus particularly on this subject because his own researches in the lunar theory have followed in some respects a parallel course. Professor Adams states that he has long been convinced that the most advantageous way of treating the lunar theory is, first, to determine with all desirable accuracy the inequalities which are independent of e, e' and γ, and then in succession to find the inequalities which are of one dimension, two dimensions, and so on with respect to those quantities. Thus, the coefficient of any inequality in the Moon's coordinates would be represented by a series arranged in powers and products of e, e' and γ; and each term in this series would involve a numerical coefficient which is a function of m alone, and which admits of calculation for any given value of m without the necessity of developing it in powers of m. This method is particularly advantageous when we wish to compare our results with those of an analytical lunar theory such as Delaunay's, in which the eccentricities and the inclination are left indeterminate, since each numerical coefficient could be compared separately with its analytical development in powers of m. As it is only the series proceeding by powers of m in

Delaunay's theory which have a slow rate of convergence, it is probable that all the sensible corrections required by Delaunay's coefficients would be found among the terms of low order in e, e' and γ.

Professor Adams proceeds: "The differential equations which would require solution in these successive operations after the determination of the inequalities independent of eccentricities and inclination would be all linear and of the same form.

"It is many years since I obtained the values of these last-named inequalities to a great degree of approximation, the coefficients of the longitude expressed in circular measure, and those of the reciprocal of the radius vector, or of the logarithm of the radius vector, being found to ten or eleven places of decimals.

"In the next place, I proceeded to consider the inequalities of latitude, or rather the disturbed value of the Moon's co-ordinate perpendicular to the ecliptic, omitting the eccentricities as before, and taking account only of the first power of γ.

"In this case the differential equation for finding z presents itself naturally in the form to which Mr. Hill reduces, with so much skill, the equations depending on the first power of the eccentricity of the Moon's orbit.

"In solving this equation I fell upon the same infinite determinant as that considered by Mr. Hill, and I developed it in a similar manner in a series of powers and products of small quantities, the coefficient of each such term being given in a finite form.

"The terms of the fourth order in the determinant were thus obtained by me on December 26, 1868. I then laid aside the further investigation of this subject for a considerable time, but resumed it in 1874 and 1875; and on December 2 in the latter year I carried the approximation to the value of the determinant as far as terms of the twelfth order, or to the same extent as that which has been attained by Mr. Hill. I have also succeeded in reducing the determination of the inequalities of longitude and radius vector which involve the first power of the lunar eccentricity to the solution of a differential equation of the second order; but my method is much less elegant than that of Mr. Hill.

"Immediately after Mr. Hill's paper reached me I wrote to him expressing my opinion of its merits, and telling him what I had done in the same direction; and I received from him a very cordial and friendly letter in reply.

"The equation which I had obtained by equating the above-mentioned determinant to zero differed in form from Mr. Hill's; and on making the reductions required to make the two results immediately comparable, I found that there was an agreement between them except in one term of the twelfth order. On examining my work I found that this arose from a simple error of transcription in a portion of my work, and that when this had

been rectified my result was in entire accordance with Mr. Hill's. The calculations by which I have found the value of the determinant are very different in detail from those required by Mr. Hill's method, and appear to be considerably more laborious."

The differential equation which determines z, the Moon's coordinate perpendicular to the equator, is

$$\frac{d^2z}{dt^2}+\left(\frac{\mu}{r^3}+\frac{m'}{r_1^3}\right)z=0.$$

This equation thus presents itself originally (as mentioned by Professor Adams) in the same form,

$$\frac{d^2w}{d\tau^2}+\Theta w=0,$$

as that to which Mr. Hill succeeds in reducing the equations upon which the inequalities involving the first power of the lunar eccentricity depend.

Professor Adams puts

$$\frac{\mu}{r^3}+\frac{m'}{r_1^3}=(n-n')^2\{q^2+2\Sigma_1^\infty q_p\cos 2p(n-n')t\}$$

and Mr. Hill puts

$$\Theta=\Theta_0+\Theta_1\cos 2\tau+\Theta_2\cos 4\tau+\&c.$$

The same determinant is, therefore, reached in both cases, and there is no great difference in the notation. Professor Adams's form of the developed value of the determinant is given on p. 47 of volume of the *Monthly Notices* referred to. By means of this developed expression, the value of g, which stands to the node in the same relation that c does to the perigee, is found to fifteen places of decimals. I may mention that in this paper Professor Adams also gives the numerical values of the terms in the expansions of $g-1$ and $c-1$ both in powers of m and of m. In each case the development in powers of m is much the more advantageous; and he states that he has found that a similar advantage results from the employment of m instead of m in the development of the Moon's periodic inequalities.

Before considering in a more general light the inferences that we may draw from the similarity of the researches of Professor Adams and Mr. Hill, I should like to draw attention to the fundamental character of Mr. Hill's infinite determinant in the lunar theory, and possibly also in other applications of mathematics.

The differential equation

$$\frac{d^2w}{d\tau^2}+\Theta w=0.$$

may be regarded as a canonical form.* Mr. Hill was led to it by

* Riccati's equation and several other well-known equations are reducible to this form, which has been much studied; but, so far as I know, the case in which Θ is a periodic series has not been considered.

considering the motion of the perigee, Professor Adams by considering the motion of the node. It is probable that many other inequalities can be made to depend upon the solution of an equation of this form. The form of Θ, viz.,

$$\Theta_0 + \Theta_1 \cos 2\tau + \Theta_2 \cos 4\tau + \&c.,$$

where Θ_p is of the $2p$th order, is very general; and so also is the method of solution by indeterminate coefficients.

The determinant in question, therefore, possesses considerable mathematical interest of its own, and its properties and development seem likely to admit of a wide application in mathematical researches in which periodic functions are involved.

The fact that the work carried out independently by Professor Adams and Mr. Hill should have run so much upon the same lines, and have so much actually in common, affords strong evidence that it is in this direction that we must look, in the present condition of the lunar theory, for any further important advances. It is almost impossible to study the writings to which I have referred without becoming impressed by this feeling. Mr. Hill puts the matter very clearly when he points out that the great majority of the mathematicians who have worked at the lunar theory have had before them, as their ultimate aim, the construction of tables; that is to say, they have viewed the problem from the standpoint of practical astronomy rather than of mathematics. This accounts for the restricted choice of variables and parameters. "Again," proceeds Mr. Hill, "their object compelling them to go over the whole field, they have neglected to notice many minor points of great interest to the mathematician, simply because the knowledge of them was unnecessary for the formation of tables. But the developments having now been carried extremely far, without completely satisfying all desires, one is led to ask whether such modifications cannot be made in the processes of integration, and such coordinates and parameters adopted, that a much nearer approach may be had to the law of the series, and at the same time their convergence augmented."

In recent years it has come to be generally believed that a worker had but little chance of performing useful service in the lunar theory unless he was prepared to make it the study of his life. The belief also has been prevalent that the mathematical portion of the treatment of the subject has been worked out, and that there was no scope for the display of mathematical skill or the employment of modern mathematical methods. Until some great discovery should change the face of the whole subject, it has seemed likely that patience and diligence in traversing with greater care the old lines, and extending still further developments already carried to a wonderful extent, would be all that was required to perfect the theory. Considering, on the other hand, the attractiveness of the new and rapidly progressing

branches of pure mathematics, and of many recent applications of mathematics to physical science, it is scarcely to be wondered at that so few of the younger generation of mathematicians should have included the lunar theory within their subjects of research. The papers of Mr. Hill's which I have described, and certain recent papers of Professor Adams's, have invested the lunar theory with a new mathematical interest, and have shown that in the treatment of the special problems included in the subject there is an ample opportunity not only for the application of existing mathematical methods, but even for the discovery of new ones. These papers show also that it is possible for the mathematician to confine himself to these special problems without attempting to cover the whole ground of the lunar theory. I hope that this is the dawn of a new day in the history of the lunar problem, and that, now that the whole territory has been mapped out by Plana and Delaunay, it will be found that the special investigations offer a tempting field to the mathematician. So far from the subject having been exhausted by the general methods which have been applied to it as a whole, I believe that the future will show that they have but cleared the ground and disclosed to view the objects to which mathematical investigation may with the greatest advantage be directed.

I have now described, though necessarily in a very imperfect manner, Mr. Hill's mathematical researches upon special problems in the lunar theory, the originality and peculiar value of which the Council have been especially desirous of recognising by the award of their medal. I can refer but briefly to Mr. Hill's other important contributions to physical astronomy, most of which, however, have been already noticed in our Annual Reports.

The American *Journal* contains two other papers of his. The first of these, in the fourth volume, is a short note on "Hansen's General Formulæ for Perturbations," in which an equation of Hansen's is expressed in a form which is not only more simple, but also more convenient for computation. The second, in the sixth volume, is entitled "On Certain Possible Abbreviations in the Computation of the Long-Period Inequalities of the Moon's Motion, due to the Direct Action of the Planets." Hansen has characterised the calculation of the coefficients of these inequalities as extremely difficult; but Mr. Hill finds that if the shortest methods are followed this is no longer the case. In this characteristic paper, Mr. Hill, following the principles which, as we have seen, have guided him in all his work, attacks the question from the very beginning by a direct analytical investigation. He thus obtains finally, not only a new method for the actual computation of the inequalities, but also some results of more purely mathematical interest.

Three elaborate memoirs have been published by Mr. Hill among the astronomical papers prepared for the use of the *American Ephemeris and Nautical Almanac* (i) "On Gauss's

Method of Computing Secular Perturbations, with an Application to the Action of *Venus* on *Mercury*" (1881); (ii) "Determination of the Inequalities of the Moon's Motion, which are produced by the Figure of the Earth: a Supplement to Delaunay's Lunar Theory" (1884); (iii) "On Certain Lunar Inequalities, due to the Action of *Jupiter*, and discovered by Mr. E. Neison" (1885).

The object of the first of these papers is to reproduce in a form practically useful for astronomers the results given by Gauss in his celebrated memoir, "Determinatio Attractionis &c." In the original memoir the method is not presented in such a manner that it admits of easy application to an actual case. In this paper Mr. Hill places Gauss's process within the reach of any computer possessed of ordinary mathematical knowledge. Gauss's investigation is reproduced in full, with the addition of the details necessary for its application; and, finally, the formulæ themselves, in the shape in which they are required by the practical calculator, as well as the necessary tables of elliptic integrals, are given. As an example, the computation of the secular perturbations of *Mercury*, produced by the action of *Venus*, are worked out; the final results agreeing very closely with those of Leverrier. It is to be hoped that this paper may have the effect of bringing into more general practical use Gauss's very beautiful and perfect method.

The second memoir is described by the author in its title as a supplement to Delaunay's Lunar Theory. At the time of Delaunay's death the inequalities caused by the disturbing action of the Sun were complete; but the small effects produced by the spheroidal figure of the Earth, and other minor portions of the subject, were untouched. Mr. Hill's object in this memoir is to supplement Delaunay's great work by determining, in a literal form, all the inequalities of the Moon which arise from the figure of the Earth to the same degree of algebraical approximation as that adopted by Delaunay in determining the solar perturbations—that is, to terms of the seventh order inclusive. The value of a constant which enters into the coefficients and depends upon the figure of the Earth is determined by an elaborate discussion of numerous pendulum experiments; and by the substitution of the values of m, e, e', γ and this constant, the numerical values of the coefficients are deduced. The whole of this elaborate investigation seems to have been carried out with great skill and care. I should mention that, in his treatment of the subject, Mr. Hill adopts in principle the usual method of applying Delaunay's theory to the determination of the lunar inequalities which are due to causes other than the Sun's action, and that there is possibly a slight imperfection in this method. It is probable, however, that the differences due to this cause are insensible.

In the third of the memoirs referred to Mr. Hill effects the determination of the coefficients of two lunar inequalities,

due to the action of *Jupiter*, to which Mr. Neison drew attention in vol. xxxvii. of the *Monthly Notices*. Mr. Hill's values of these coefficients do not agree with those assigned to them by Mr. Neison. In the case of the second inequality Mr. Hill's value amounts to only about one-tenth of Mr. Neison's.

It is nine years since Mr. Hill undertook for the office of the *American Ephemeris and Nautical Almanac* an investigation of the motions of *Jupiter* and *Saturn*, with the view of constructing tables of these two planets. From its commencement this great work has occupied nearly the whole of his time; and, even if no hindrance occurs, it must continue to do so for the next three or four years. It is well known that the theory of *Saturn* is in an unsatisfactory state, Leverrier's tables failing to represent adequately the observations. A special interest therefore attaches to these new investigations which have been carried out by means of Hansen's very refined methods. The work has so far progressed very satisfactorily. The final expressions for the co-ordinates of the two bodies, together with the details of a preliminary comparison of them with observations made for the purpose of ascertaining what corrections the perturbations might need on account of errors in the provisionally assumed elements, were published last year in the "Astronomische Nachrichten" (Nos. 2,705–2,706). When these investigations, in which the approximations are carried to a much greater extent than in any previous treatment of the subject, are completed, the whole will form by far the largest and most complete investigation of the kind that has yet been performed on the American continent.

It is doubtless due to the engrossing character of this work that only two chapters of the "Researches on the Lunar Theory" were published. There is abundant evidence that Mr. Hill's researches must have been extended far beyond those given in these two chapters at the time when his new labours deprived him of the leisure necessary for completing and preparing them for press; and I trust that when the Theory and Tables of *Jupiter* and *Saturn* shall have been published, Mr. Hill may be enabled to resume his mathematical researches at the point at which their publication ceased, and to carry out his original intention to its full extent.

The President then, delivering the Medal to the Foreign Secretary, addressed him in the following terms:

Dr. Huggins,—May I ask you in transmitting this medal to Mr. Hill to assure him of our high appreciation of the value of his contributions to physical astronomy, and to express to him our earnest hope that his life may long be spared, and that he may have health and strength to complete the splendid work upon which he is now engaged, and to enrich our science still further by his mathematical researches.

The meeting then proceeded to the election of the Officers and Council for the ensuing year, when the following Fellows were elected:—

President.

J. W. L. Glaisher, Esq., M.A., F.R.S.

Vice-Presidents.

Arthur Cayley, Esq., M.A., LL.D., D.C.L., F.R.S., Sadlerian Professor of Pure Mathematics, Cambridge.
W. H. M. Christie, Esq., M.A., F.R.S., Astronomer Royal.
The Earl of Crawford and Balcarres, F.R.S.
Edwin Dunkin, Esq., F.R.S.

Treasurer.

A. A. Common, Esq., F.R.S.

Secretaries.

E. B. Knobel, Esq.
Lieut.-Col. G. L. Tupman, R.M.A.

Foreign Secretary.

William Huggins, Esq., LL.D., D.C.L., F.R.S.

Council.

Capt. W. de W. Abney, R.E., F.R.S.
J. C. Adams, Esq., M.A., LL.D., D.C.L., F.R.S., Lowndean Professor of Astronomy, Cambridge.
J. Rand Capron, Esq.
G. F. Chambers, Esq.
J. R. Hind, Esq., LL.D., F.R.S., Superintendent of the *Nautical Almanac*.
E. W. Maunder, Esq.
Capt. William Noble.
Rev. S. J. Perry, F.R.S.
A. Cowper Ranyard, Esq., M.A.
E. J. Stone, Esq., M.A., F.R.S., Radcliffe Observer.
Lieut.-Gen. J. F. Tennant, R.E., F.R.S.
H. H. Turner, Esq., B.A., B.Sc.